



# *Mobility Demonstrator*

*22 August 2013*

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## Objective



- **Presentation of the Mobility Demonstrator effort which exercised a “paradigm shift” in TARDEC Mobility's traditional methodology / thinking regarding combat vehicle mobility design.**
- **Exercising of atypical methods to stimulate creativity.**
- **Focus on innovative / creative thought towards mobility systems.**
- **Perform a subsystem-by-subsystem evaluation of the art of the possible.**



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# Engineers Gone Wild !

## Exercise I



- TARDEC Engineers sequestered and tasked to concept a new vehicle.
- Requirements - Futuristic, highly mobile, 40 ton weight.
- Concepts to be grounded in some reality, albeit innovative to the point of science-fiction.
- To be “safe”, engineers developed short , medium, and long-range concepts.
- Engineers found lack of defined requirements “stressful”.



*Wheeled  
Conventional Design*



*Quad Tracked  
Vehicle*



*Modular/Detachable Center  
Pod & Scouts Vehicle*



*Highly Articulated  
Wheeled Vehicle*



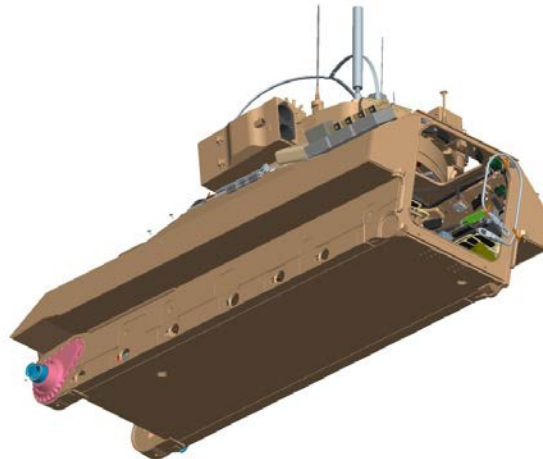
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# Wheels on a Bradley !

## Exercise II



- **Mechanical Track Drive / Electric Wheeled Drive Approach**
- **Modular Mechanical Track Running Gear**
- **Modular Electric In-Hub Motor Wheels with External Hydraulic Suspension Unit (HSU) Running Gear System**
- **Both systems fit in same sponson cavity location.**





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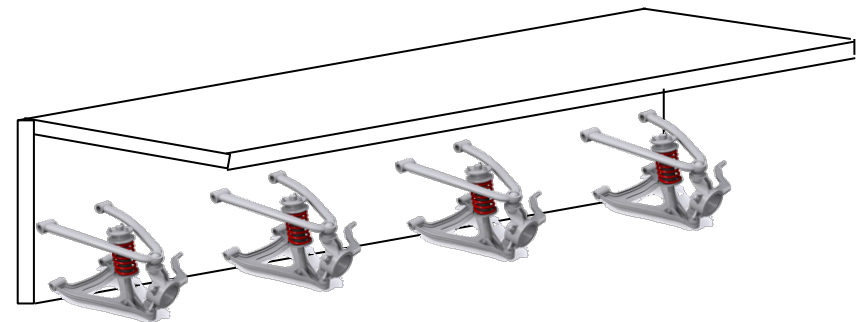
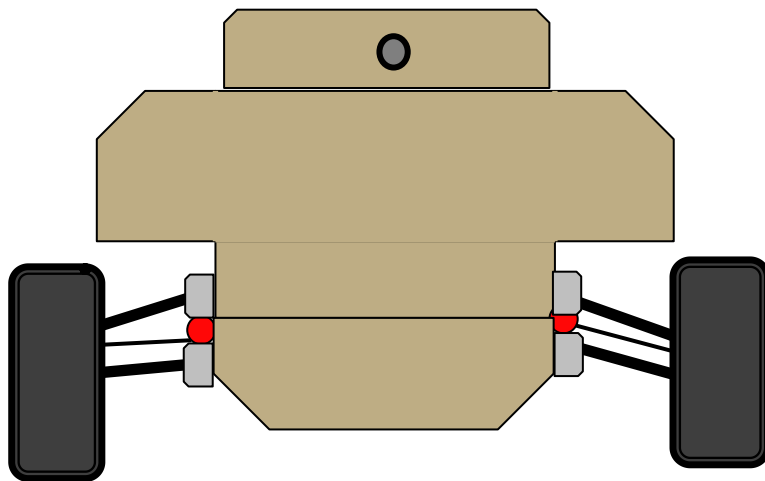
# Tracked Modular Suspension





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# Wheeled Modular Suspension





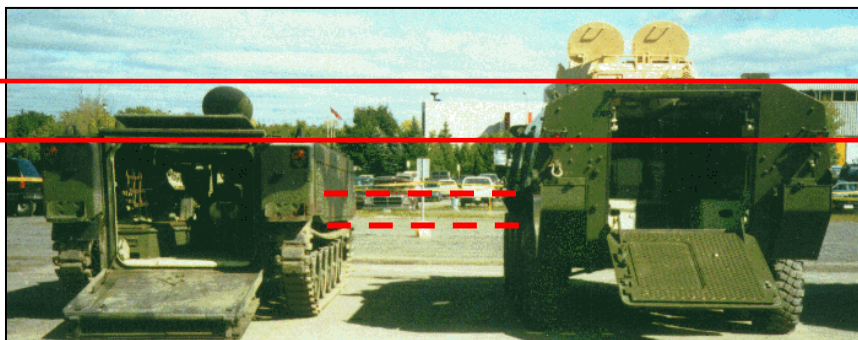


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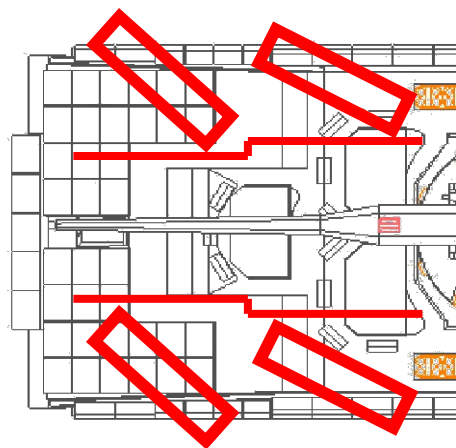
# Chassis Configuration Challenges



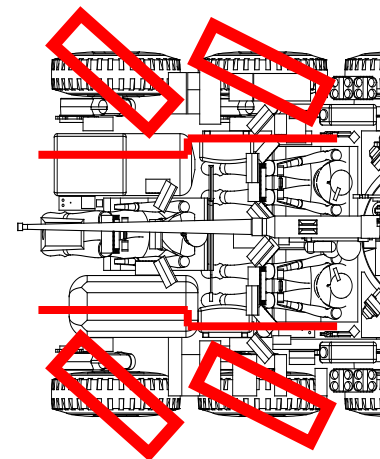
Sponsons



Vehicle Heights



Ackerman Steering Volume Requirements

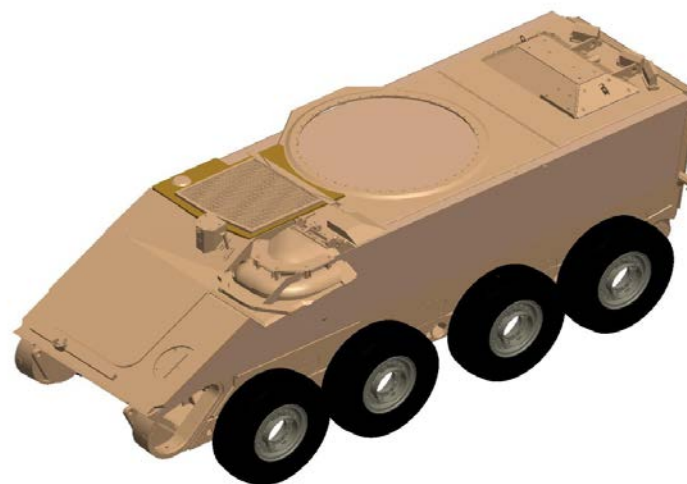
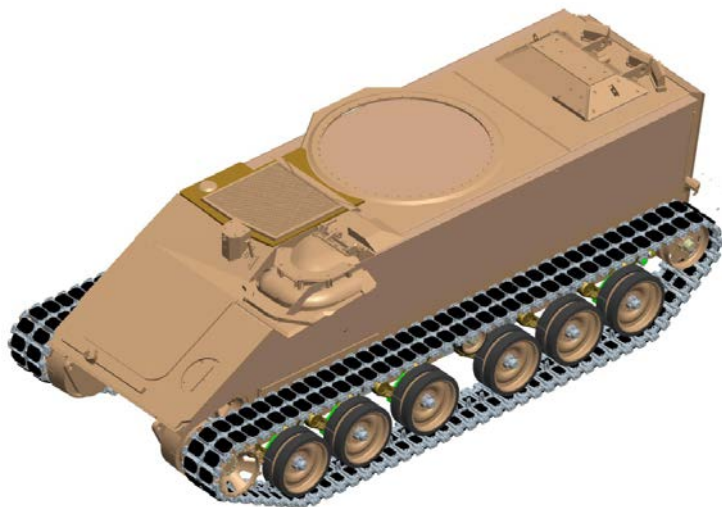


**Converting tracked vehicle to wheels requires raising vehicle and / or widening vehicle wheelbase**



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# Bradley with Sponsons Removed





- 17-19 December 2012 – TARDEC Innovation Event
- Purpose: To collaborate and develop new mobility and situational awareness ideas for combat tracked and wheeled vehicles using latest Mobility Demonstrator Guidance.
- Participants:
  - 4 Chief Warrant Officers from the U.S. Army Ordnance Center and School.
  - 11 College of Creative Studies Associate Professor and Students
  - 11 TARDEC Engineers
- Concept a theoretical “Mobility Demonstrator” military vehicle with flexible / reconfigurable running gear system capable of converting between tracks and wheel modes.
- Agnostic to either wheels or tracks during the assembly process.
- Focus on future commonality of mobility components and systems.
- Maximum 40 ton weight.
- Military environment.
- Be novel, creative, anything goes.



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# Tracked Military Vehicles





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# Wheeled Military Vehicles





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# Performance Comparisons



Greater Vehicle Weights  
Faster Pavement Road Speed  
Lower Ground Pressure  
Greater Vertical Climb  
Greater Trench Crossing

Wheels

X

Tracks

X

X

X

X

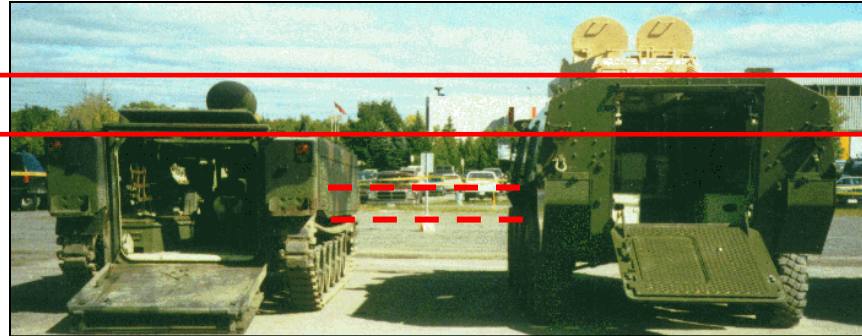


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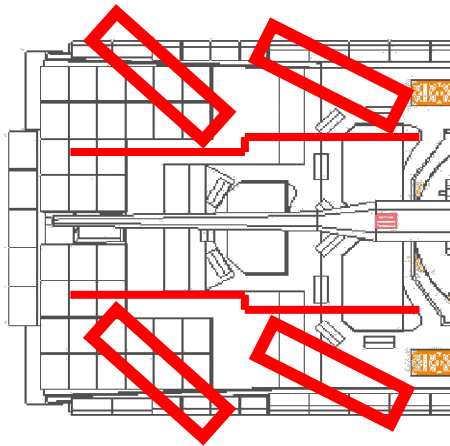
# Chassis Considerations



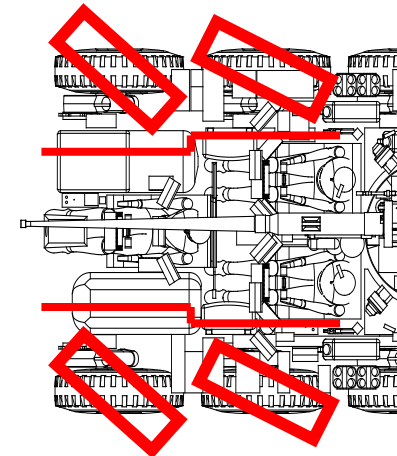
Sponsons



Vehicle Heights



Ackerman Steering Volume Requirements



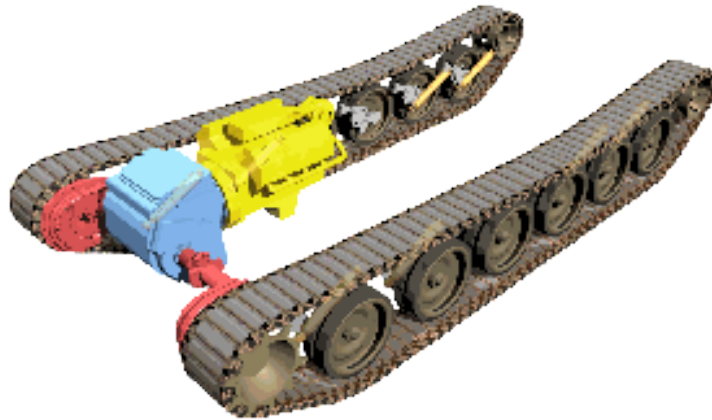


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# Configuration Considerations – Complexity



Tracks



Wheels



**Wheeled Vehicles have a More Complicated Running Gear System, but Tracked Vehicles have a More Expensive Running Gear System**



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# Vehicle Summary Pros / Cons



## **TRACKS**

### ADVANTAGES:

- Higher Cross Country Speeds
- Superior Obstacle and Gap Crossing
- Increased Slope Climbing Capability
- More Compact / Lower Silhouette

### DISADVANTAGES:

- Higher Production, Maintenance, and Repair Costs
- Fewer Commercial Components
- Not Efficient in Sustained Highway Travel
- More Vibration on Hard Surface

## **WHEELS**

### ADVANTAGES:

- Capable of Maintaining Higher Speeds on Roads
- More Fuel Efficient (over Hard Surfaces)
- Less Cost Per Mile of Operation (over Hard Surfaces)
- Ability to Use Commercial Components
- Reduced Production Costs (Below 20 tons)
- Lower Maintenance and Repair Costs

### DISADVANTAGES:

- Less Obstacle and Gap Crossing Capability
- Requires Stockage of More Spare Parts
- Less Stable Gun Platform (Tire Flex)
- Poor Soft Soil Performance over 25 tons



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# We Want Both





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# Vehicle Width can be a Problem



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## Vehicle Length can be a Problem



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# Sometimes the Road is too Narrow



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# Sometimes the Road Fails





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# Sometimes the Road is Rough



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# Sometimes the Vehicles Fail



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A lot



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# The Road may be Unstable



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# The Road may Collapse



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# The Bridge may be Unsafe



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# May not Trust the Bridge



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# May want to Swim



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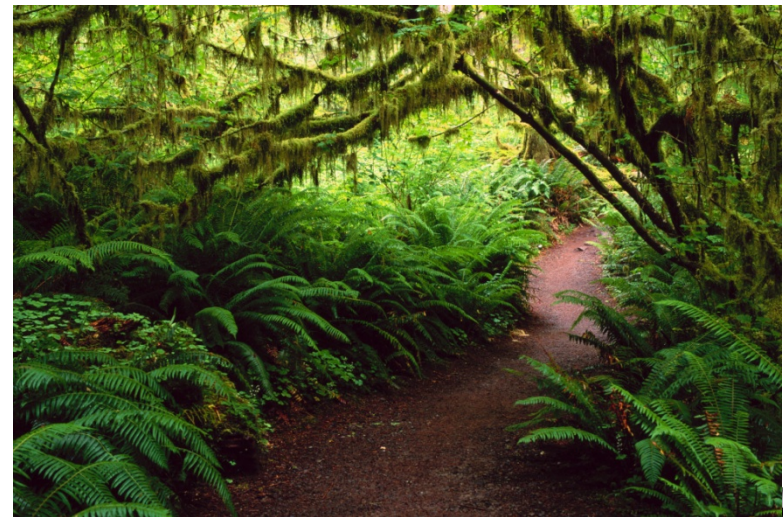
# Traverse All Terrains





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# In All Climates





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# Mud can be an Issue for Wheels



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# Mud Can be an Issue for Tracks





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# Too Much of a Good Thing



US Super Heavy Tank T-28



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## Sometimes the Driver is Wild





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# Sometimes Old Way still Works



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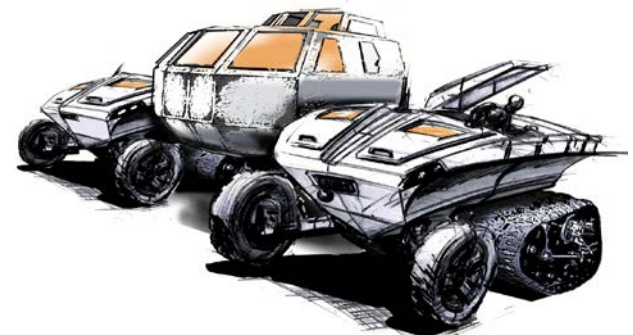


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Dropship Horizon 2012

Good Luck and  
Be Creative





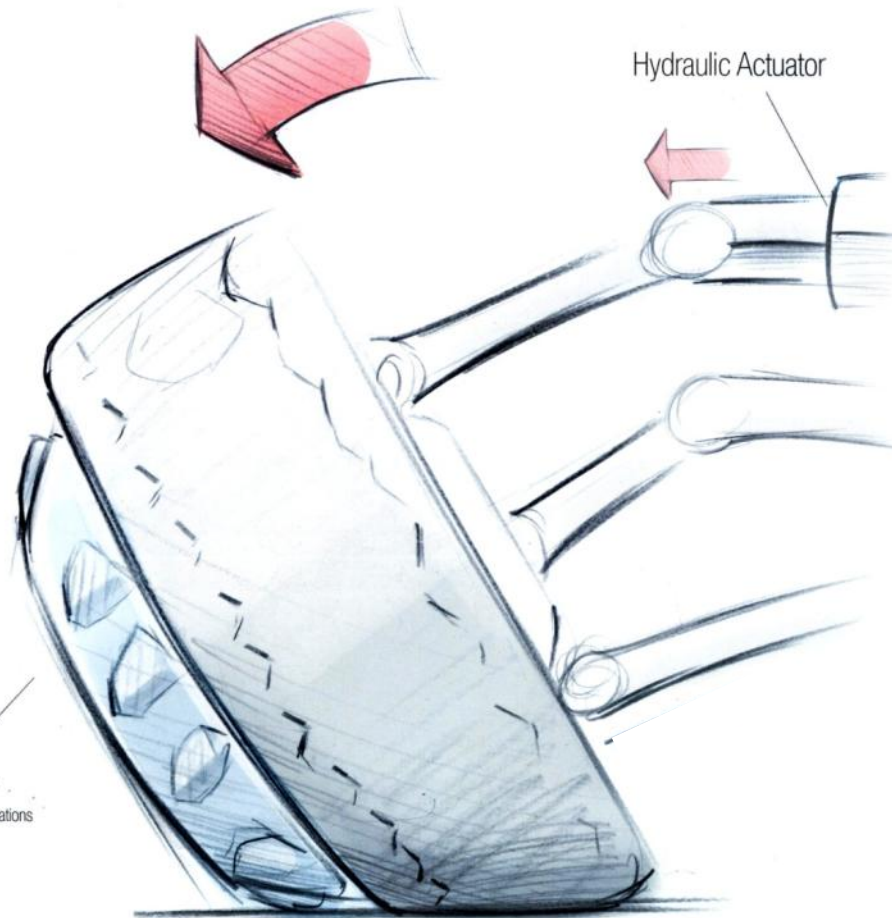
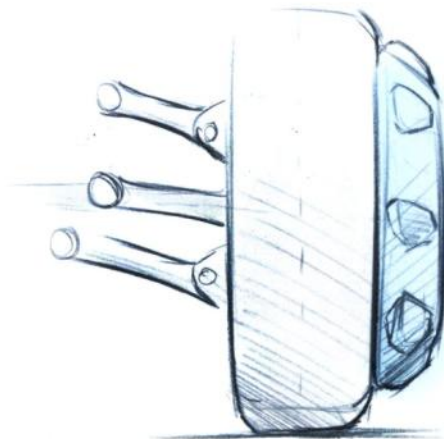
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# CCS - Mobility Demonstrator Ideations



## Wheel Articulation

-Can be built on existing Striker platform



Traction Cover

-Can be used to climb out of tricky situations



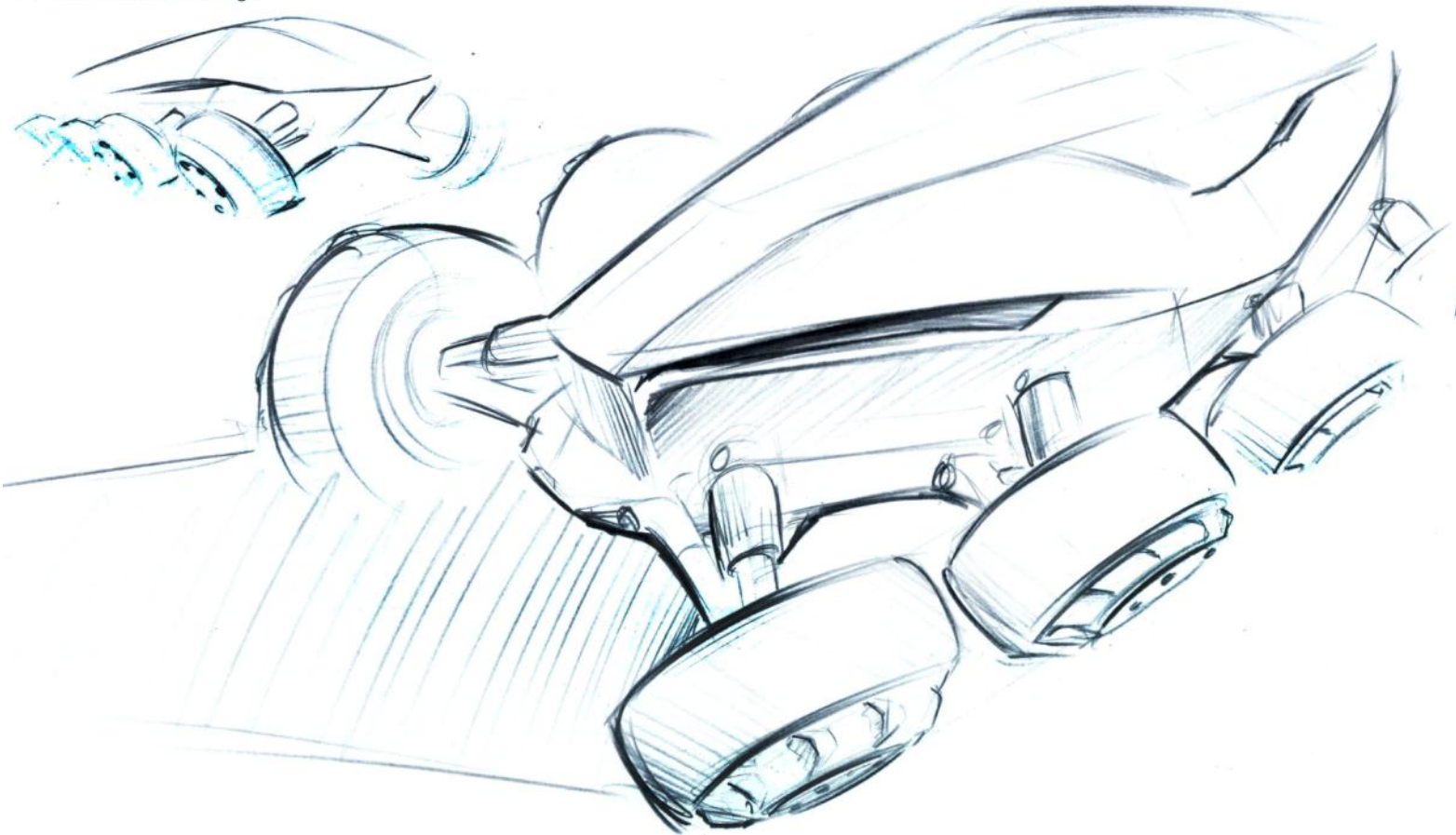
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# CCS - Mobility Demonstrator Ideations



## Final View

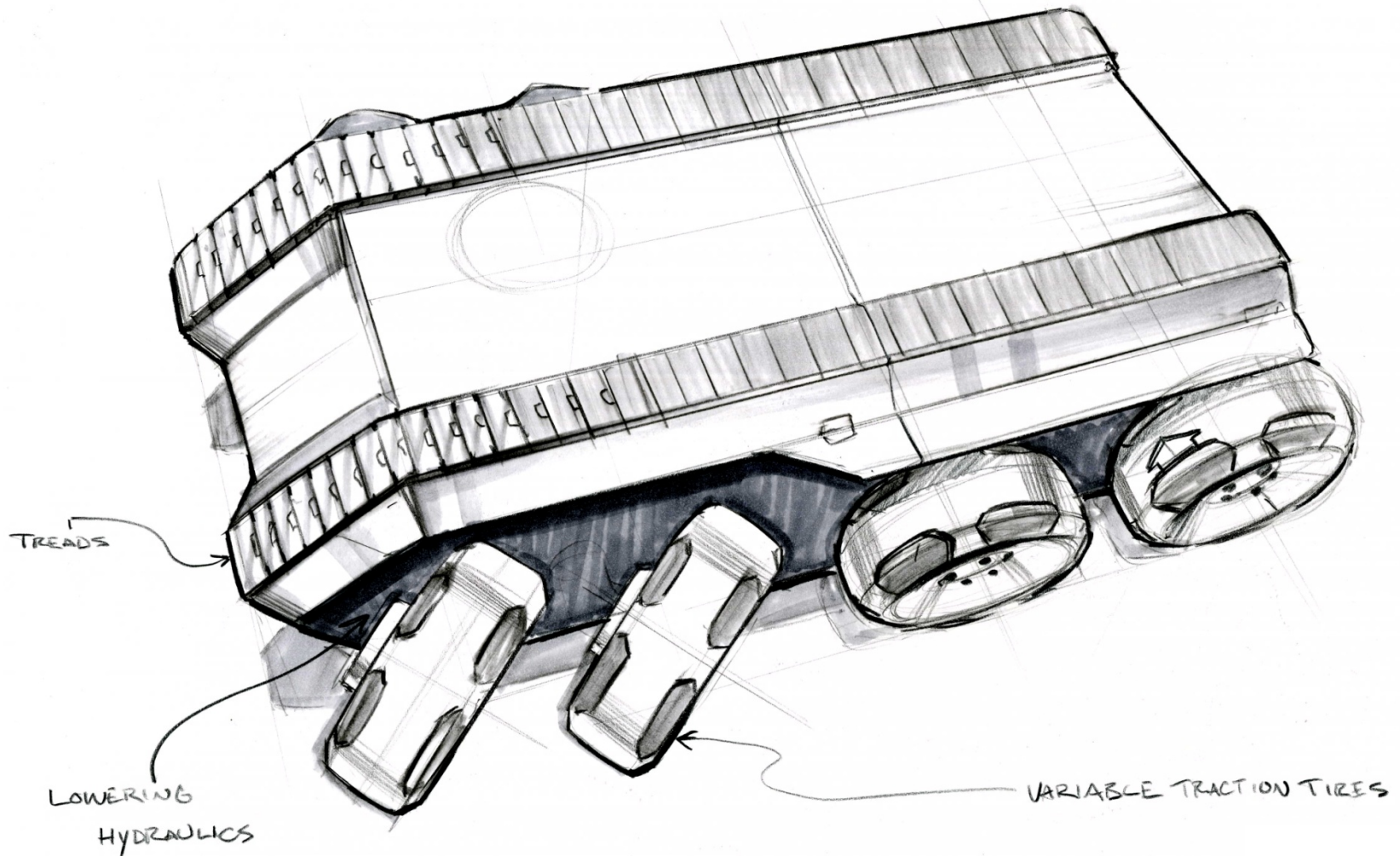
-Positive Camber Design





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# CCS - Mobility Demonstrator Ideations



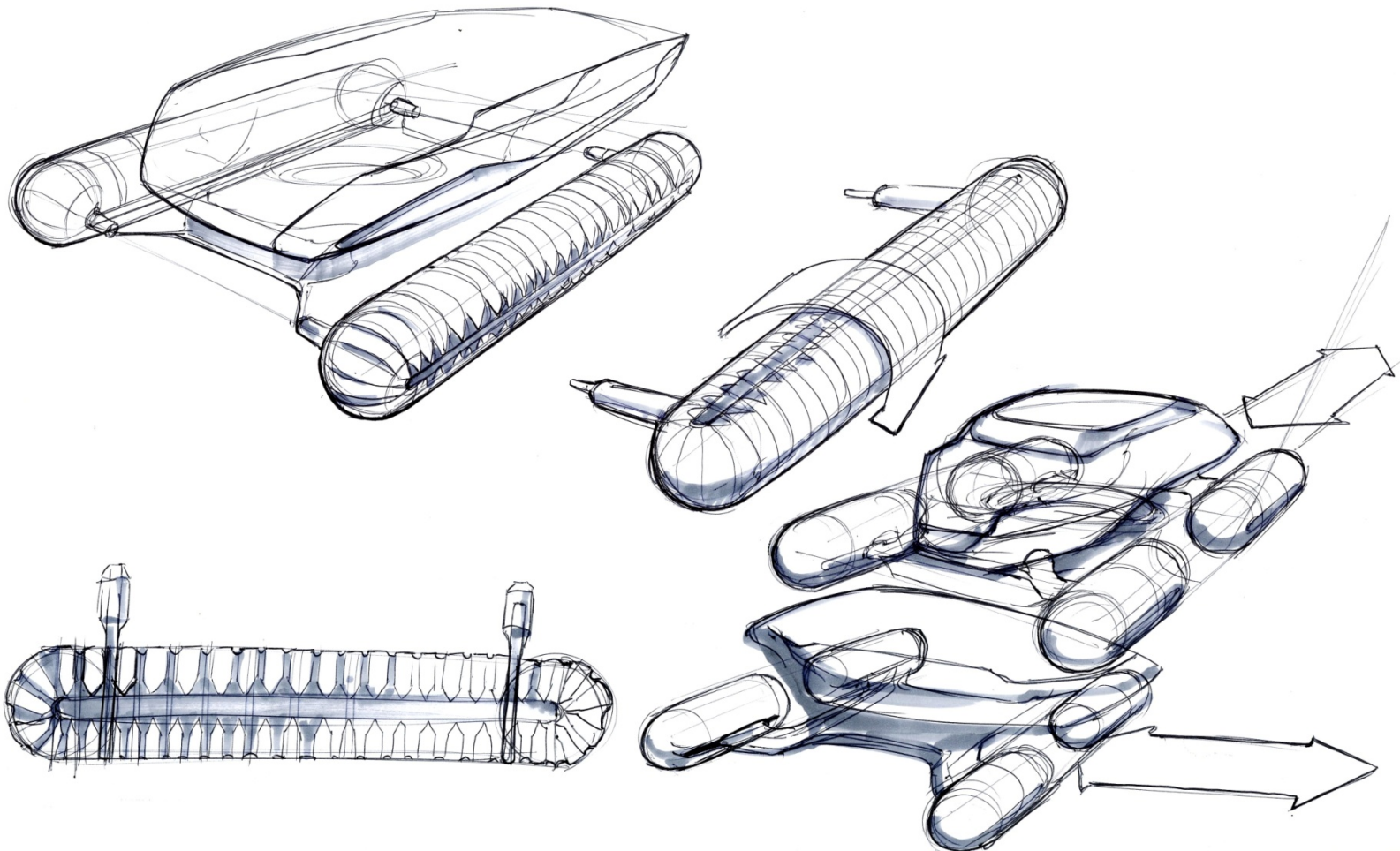


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# CCS - Mobility Demonstrator Ideations



HYBRID TRACK/WHEELS



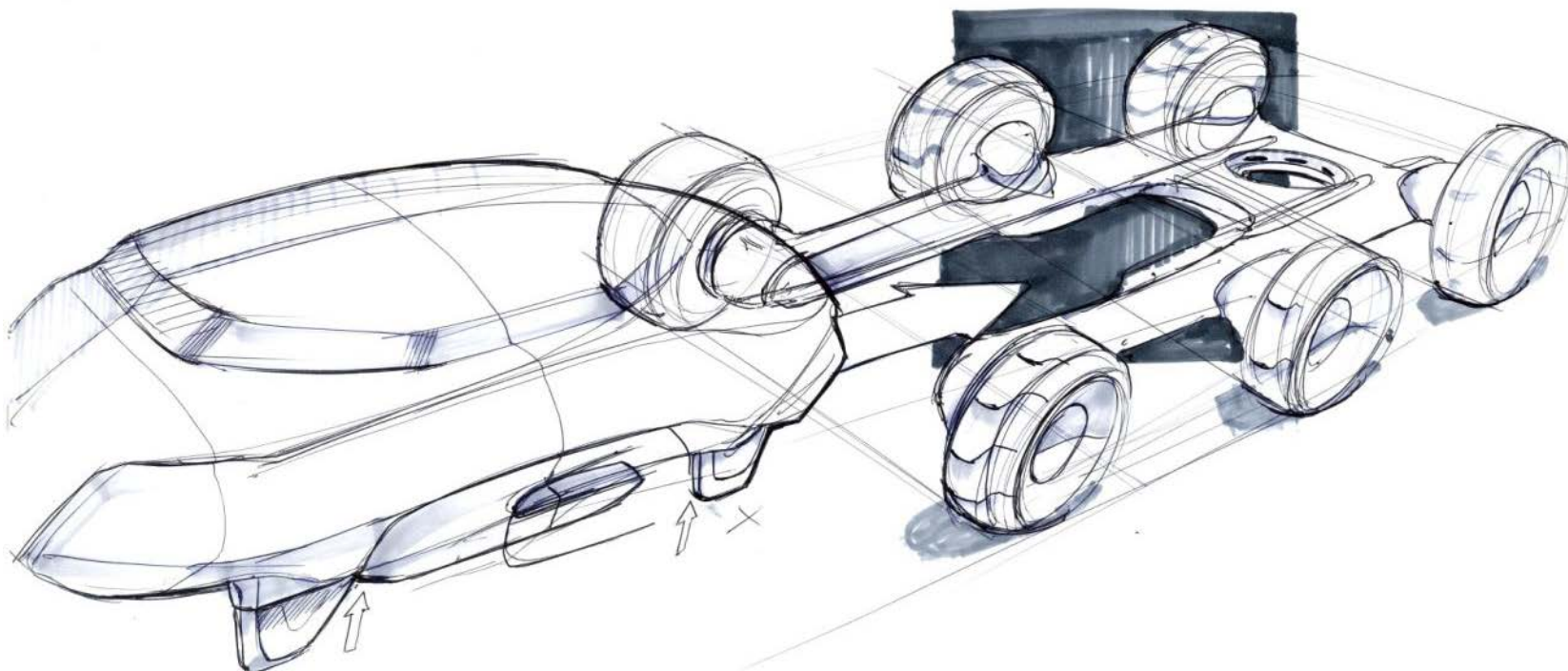
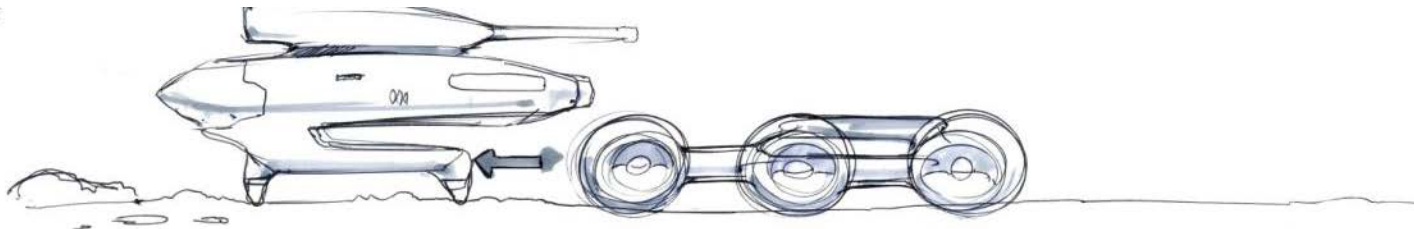


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# CCS - Mobility Demonstrator Ideations



WHEELS





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# CCS - Mobility Demonstrator Ideations

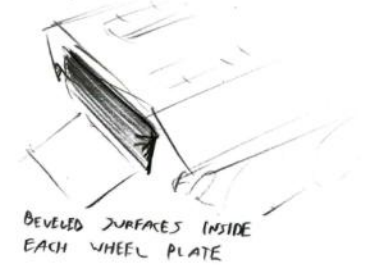
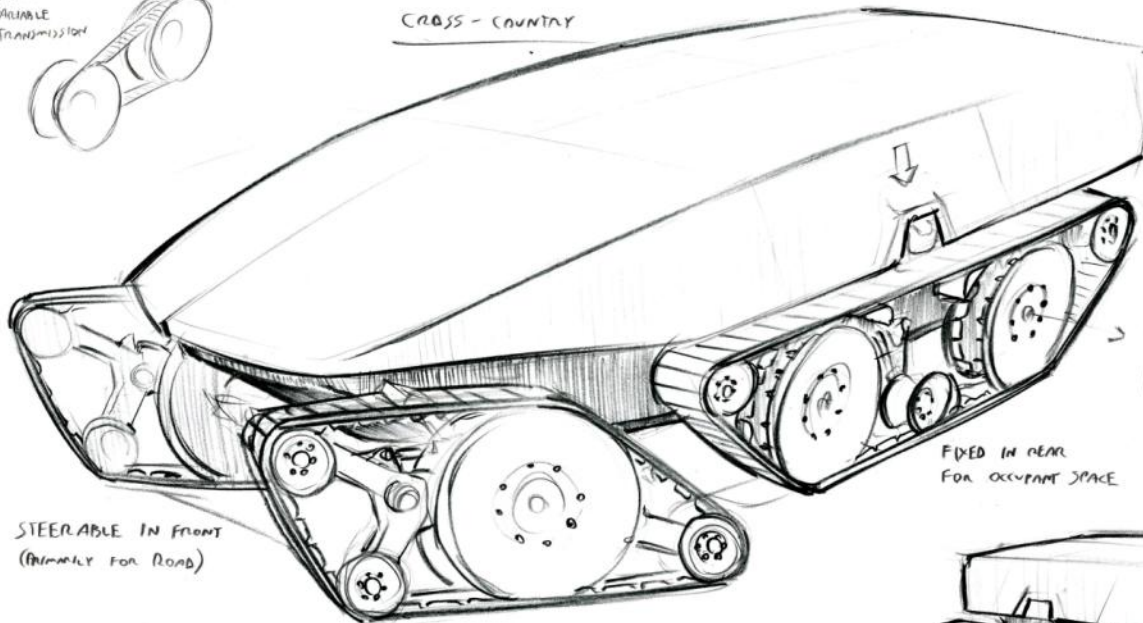


## CVT TREAD

CONTINUOUSLY  
VARIABLE  
TRANSMISSION

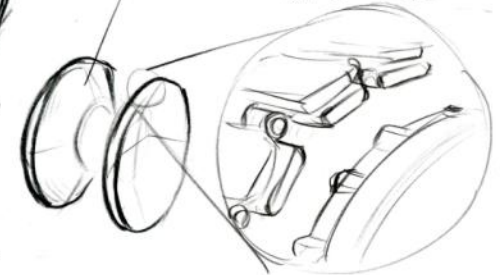


CROSS-COUNTRY



BEVELED SURFACES INSIDE  
EACH WHEEL PLATE

ENGAGEMENT SURFACE INSIDE  
LIP OF WHEEL



FIXED IN REAR  
FOR OCCUPANT SPACE

STEERABLE IN FRONT  
(Primarily for Road)

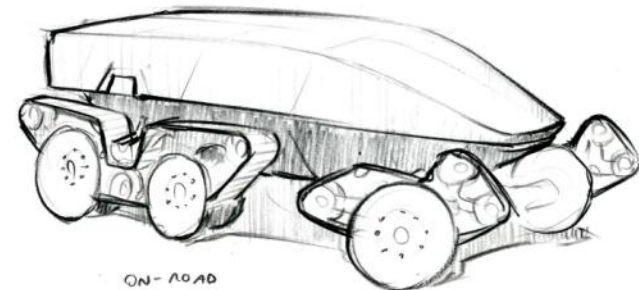
UP



TRANSITION



DOWN



ON-ROAD



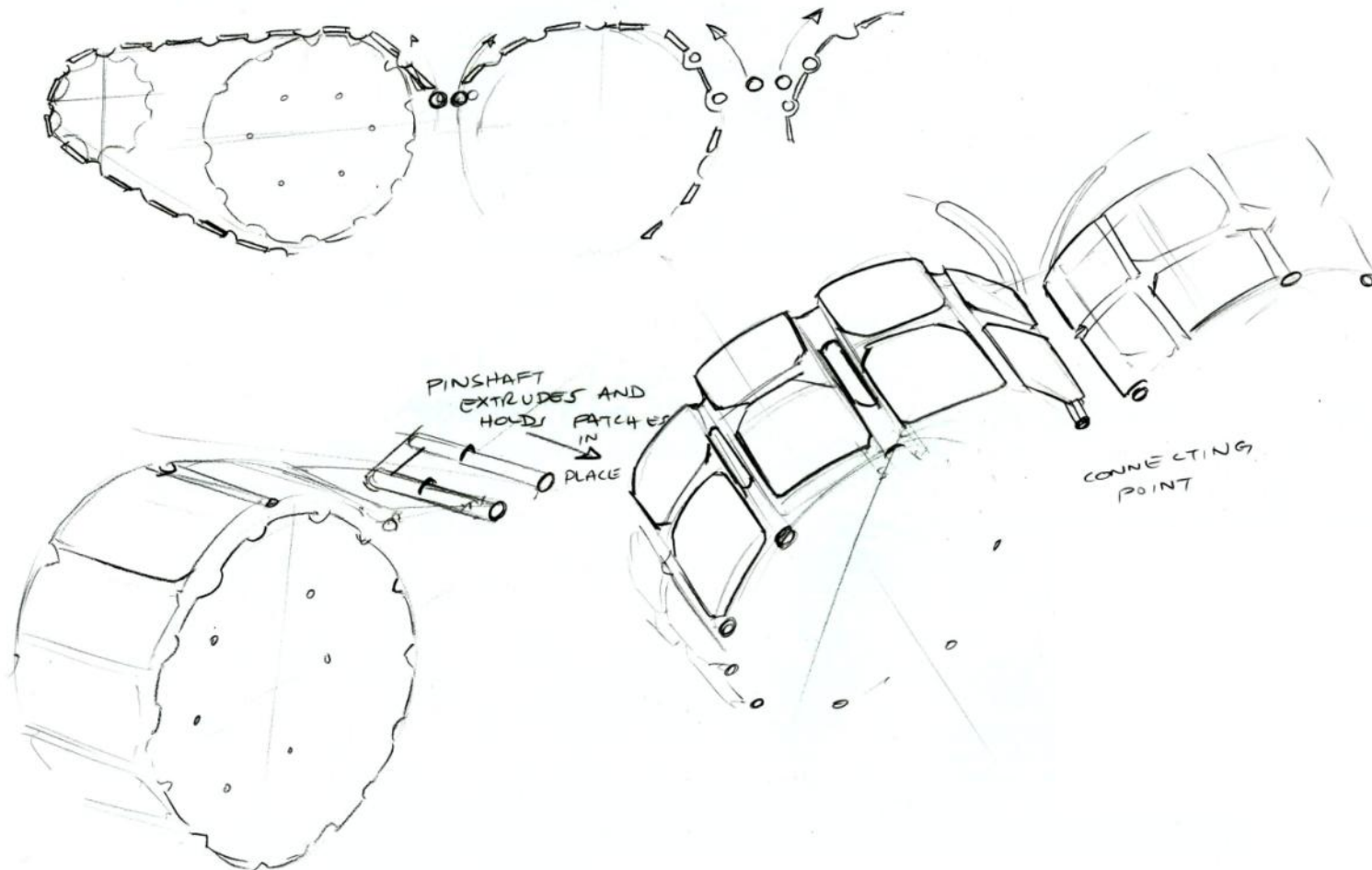
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# CCS - Mobility Demonstrator Ideations



## INTEGRATED WHEEL TRACKS

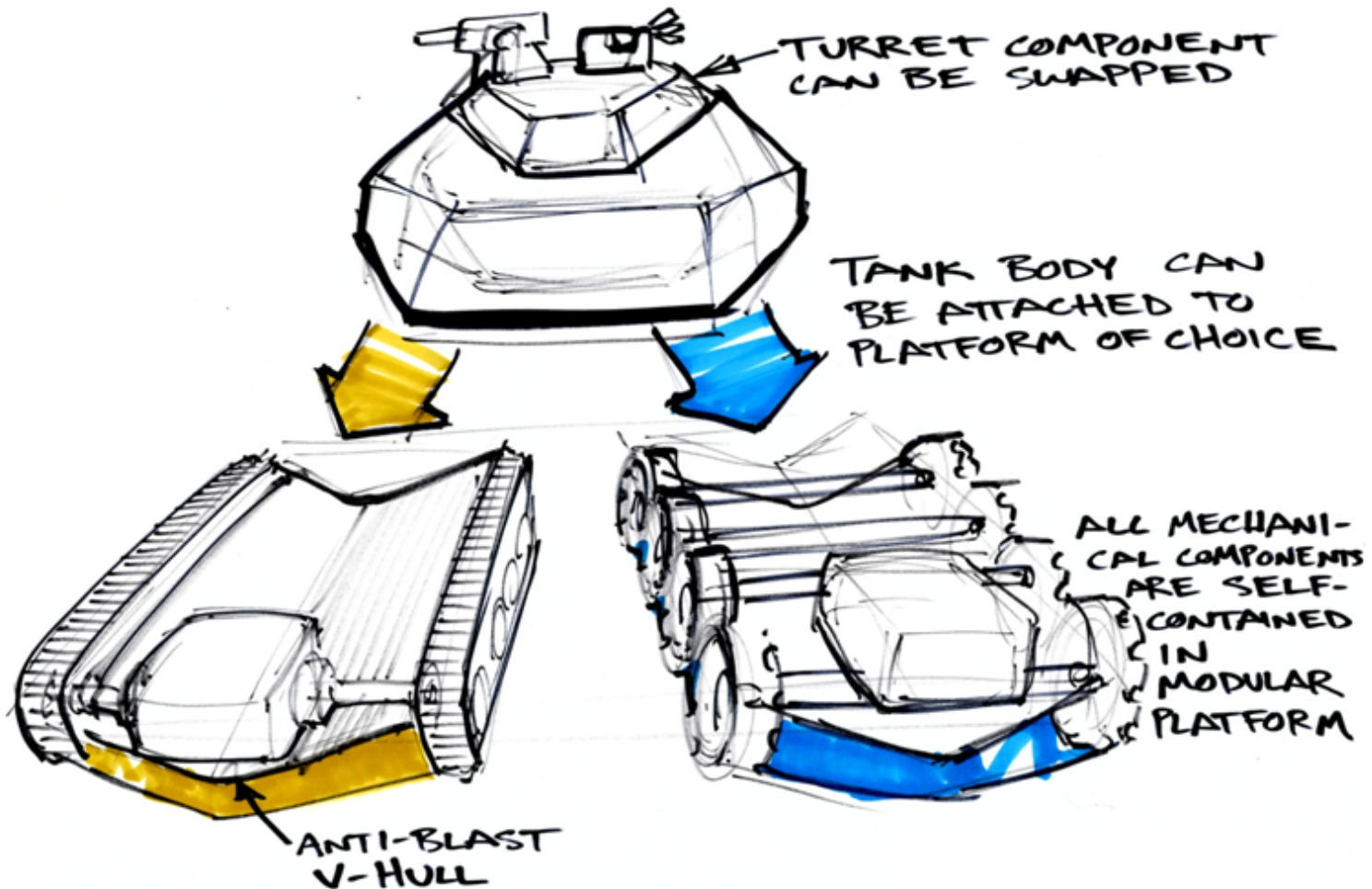
ASSEMBLY IS THE MAIN ISSUE





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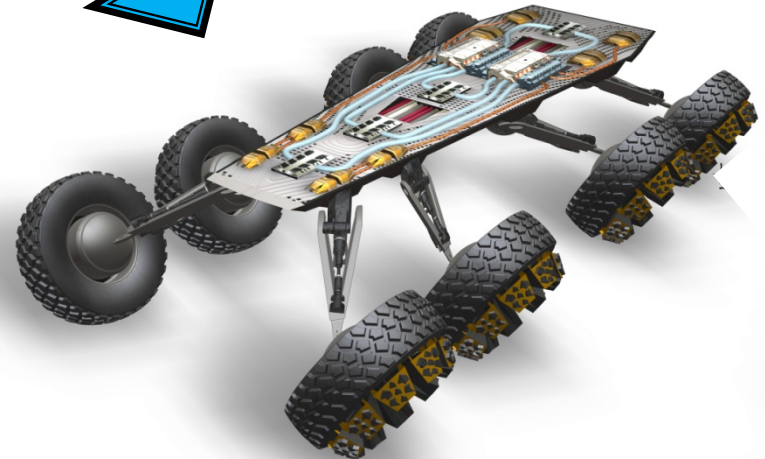
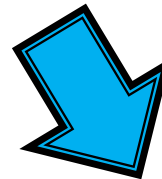
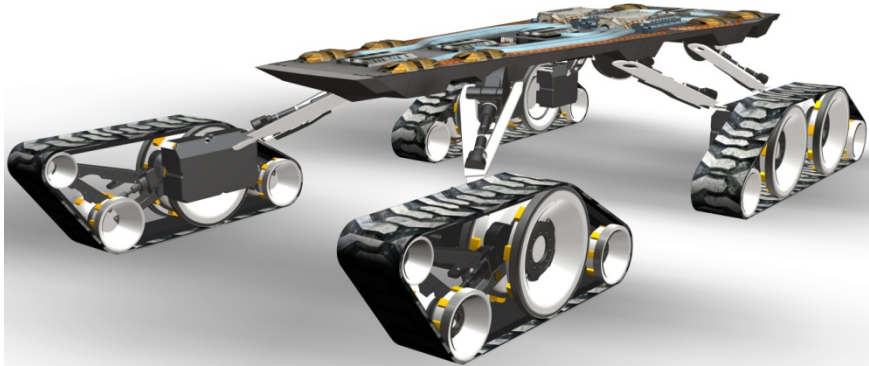
# Body-On-Carrier Concept Vehicle or Modular Chassis Concept



Tracked or Wheeled Carrier  
can be used depending on  
mission



Tracked or Wheeled  
solution can be  
integrated at the  
Depot or Assembly  
Line level





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# Body-On-Carrier Concept Vehicle or Modular Chassis Concept





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# Body-On-Carrier Concept Vehicle Wheeled Solution





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# Body-On-Carrier Concept Vehicle Wheeled Solution





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# Body-On-Carrier Concept Vehicle Tracked Solution





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# Path Forward Concepts

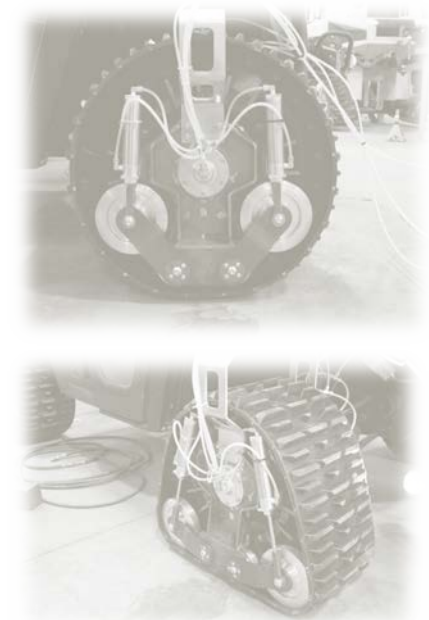
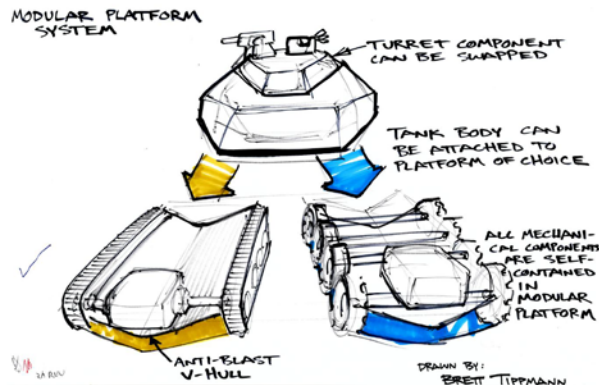
## Exercise IV



COA I – Modular Chassis

COA II – Modular Running Gear System

COA III – “Morphing” Track to Wheels System





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# Initial Mobility Demonstrator Concept



COA III – “Morphing” Track to Wheels System



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# Sequestration Wheel Concept Vehicle





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# Sequestration Tracked Concept Vehicle



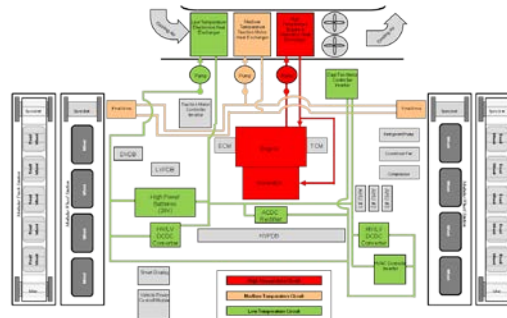
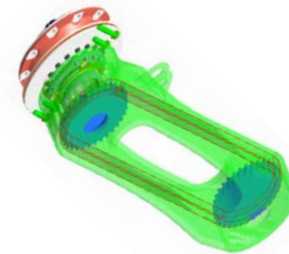


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# Subsystem-by-Subsystem Evaluation Exercise V



- Wheels to Track Transformation Sub Systems
- Advanced Suspension Sub Systems
- Advanced Power Pack Sub Systems
- Advanced Thermal Management Systems
- Electrified Propulsion Systems
- Advanced Energy Storage Systems





## Tire To Track Transformation Sub Systems





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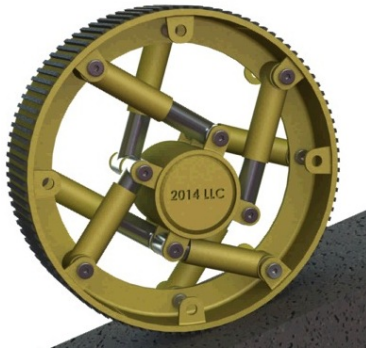
# Future Airless Wheel Technologies



Company: Structural Dynamics Cons. Eng. Co

Technology: Shwheel Tire /Shock-Wheel

Description: Rigid wheel with attached tread connected with shock absorbers between wheel and hub.



Company: Resilient Technologies (Polaris Defense)

Technology: Non-Pneumatic Tire

Description: Airless Tire/wheel with honeycombed shaped polymer supporting structure between tread and hub.



Company: Michelin

Technology: TWEEL Airless Tire

Description: Airless tire/wheel with polymer spokes between tread and hub.



Company: Scitech Industries

Technology: Airless Tire

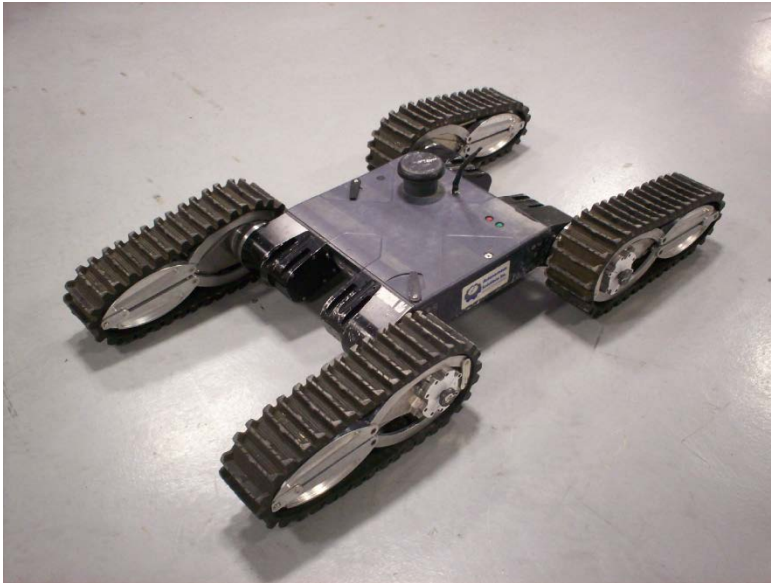
Description: Airless tire which uses U-shaped springs made of epoxy or fiberglass to mechanically support the load



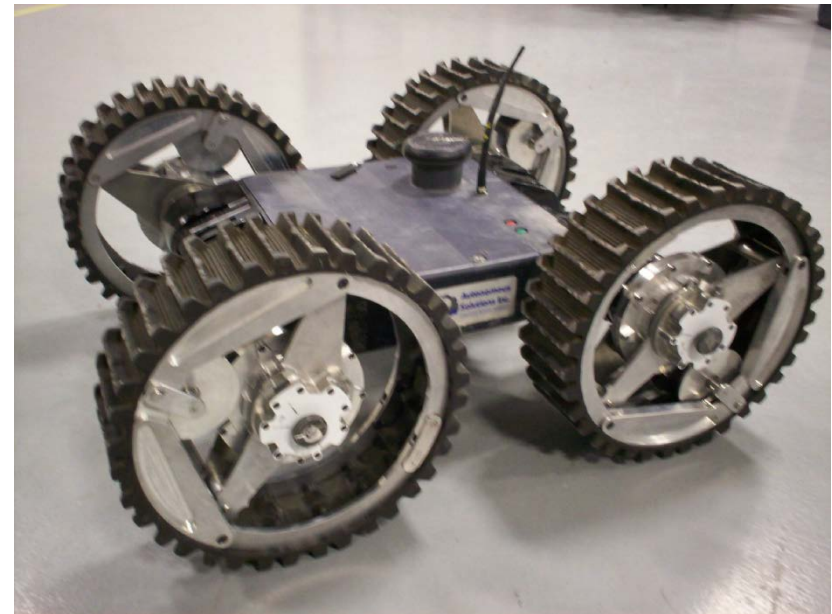


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# Roadrunner Tire to Tracks System



Roadrunner by Autonomous Solutions





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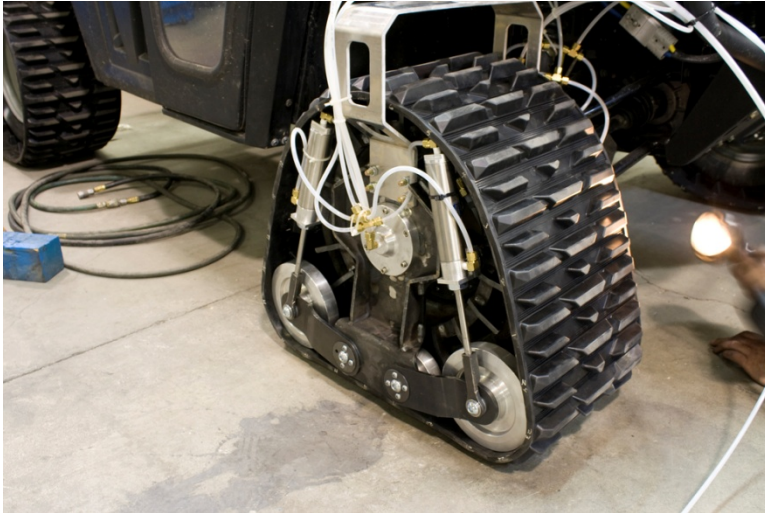
# Track –N– Go System





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# MATTRACKs Tire to Track Transformation System





## Advanced Suspension Sub Systems



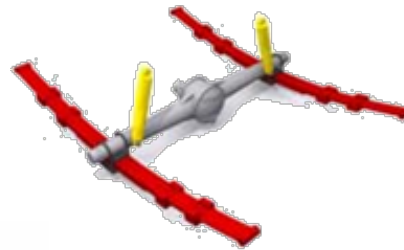
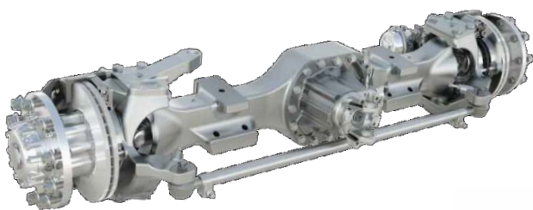


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# Tactical Suspension Technologies



- Wheeled vehicle suspension systems continue to evolve over past 50 years:
  - Independent suspensions
  - Dependant suspension (solid axles)
  - Trailing arms
- The biggest advancement in these systems has been in controls development.
- Suspension control systems have been used to improve ride and handling.
- Controls are now being developed to improve occupant safety through ride height adjust.



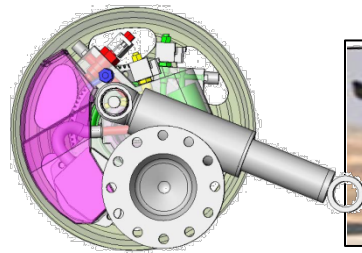
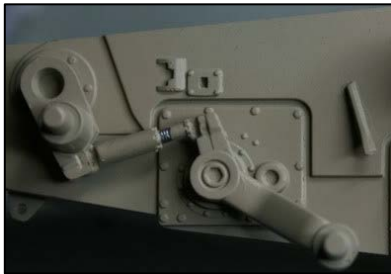


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# Combat Suspension Technologies



- Tracked vehicle suspensions continue to evolve over the past 70 years.
  - Trailing arm suspensions with torsion bar springs.
  - Either linear or rotary dampers
  - Simple linear track tensioners or self-adjusting track tensioners
- The biggest advancement in these systems has been pneumatic external road-arm design (external suspensions).
- There has been some research into semi-active suspension control systems to improve ride, but nothing fielded.



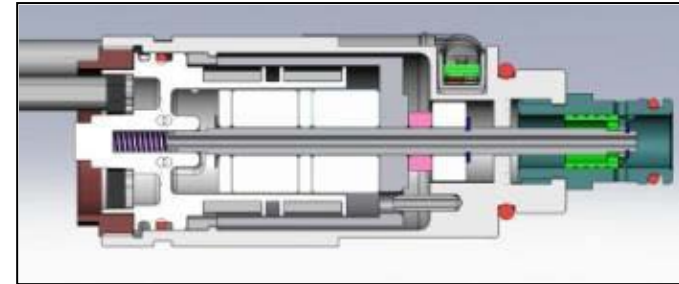


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# Adaptable Suspension Technologies



- Types / levels of vehicle suspension systems
  - Passive
  - Semi-Active (Dampers are controlled)
  - Fully-Active (Springs and/or dampers are controlled)



Variable Orifice  
- Semi-active option -

## Passive Suspension

- Fixed Spring and Damper Rates
- Trade-off between Ride Quality and Handling



## Semi-Active Suspension

- Low power solution
- Variable damping
- Improved ride quality and handling



- Add controller
- Add valve assembly

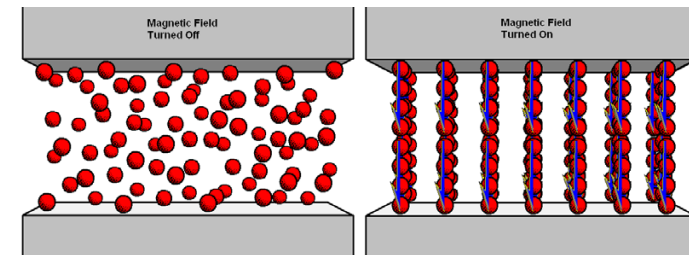


## Fully Active Suspension

- Variable ride height
- Energy recovery
- Maximum improvement in ride quality and handling



- Add motor controllers, DC-DC converter, energy storage
- Add motor assembly



Magneto-Rheological Fluid  
- Semi-active option -

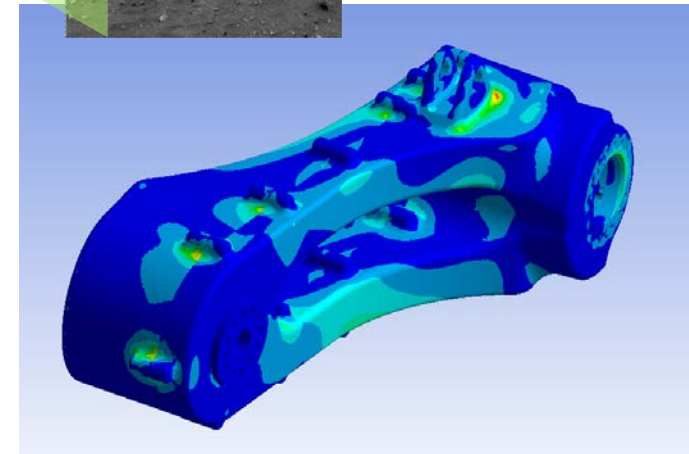
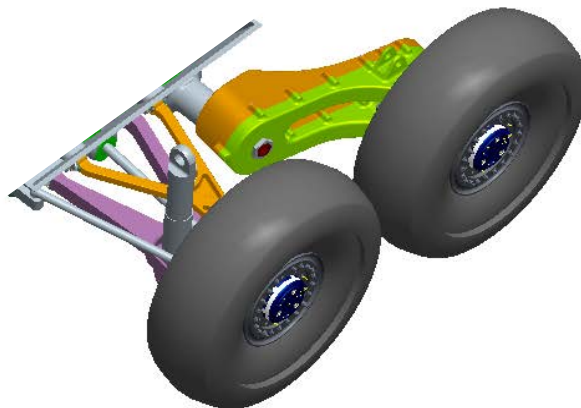
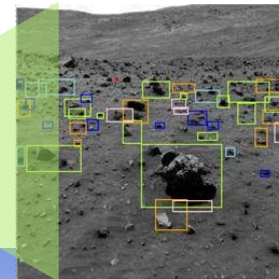
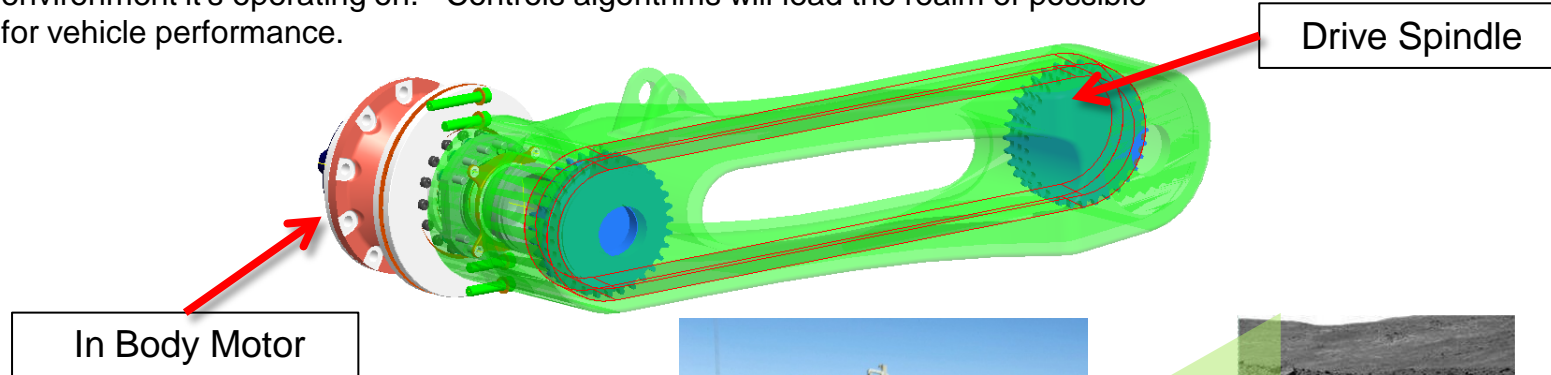


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# Advanced Suspension Systems



Suspension technology will evolve to become fully predictive of the terrain environment it's operating on. Controls algorithms will lead the realm of possible for vehicle performance.



FAULT REP



## Advanced Power Pack Sub Systems





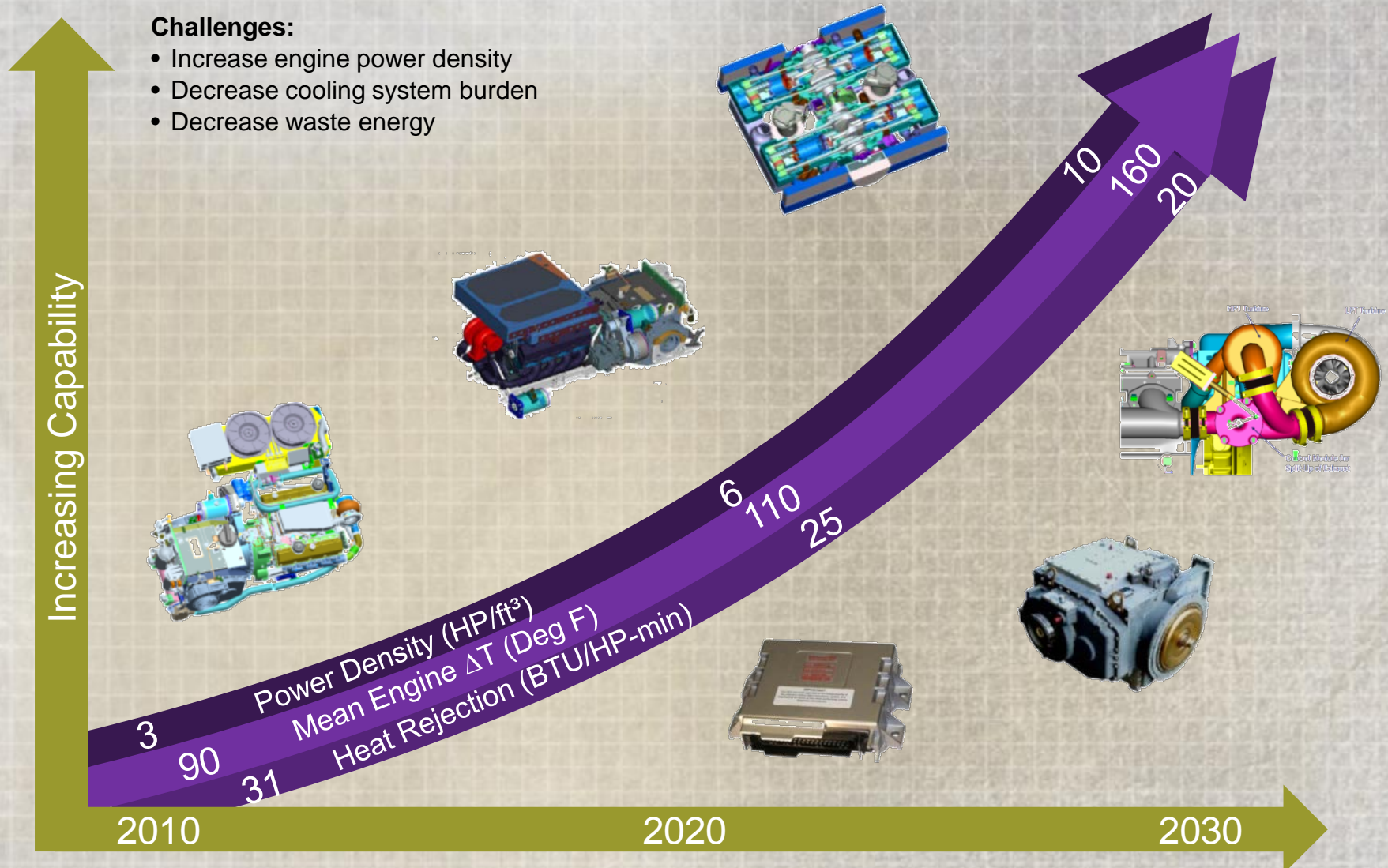
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# Power Plant Challenges



## Challenges:

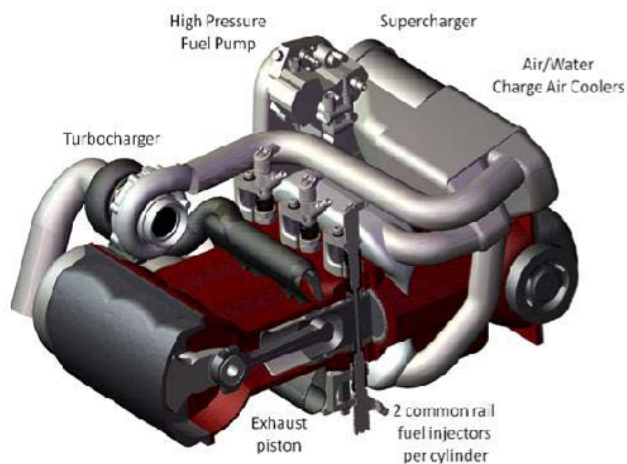
- Increase engine power density
- Decrease cooling system burden
- Decrease waste energy



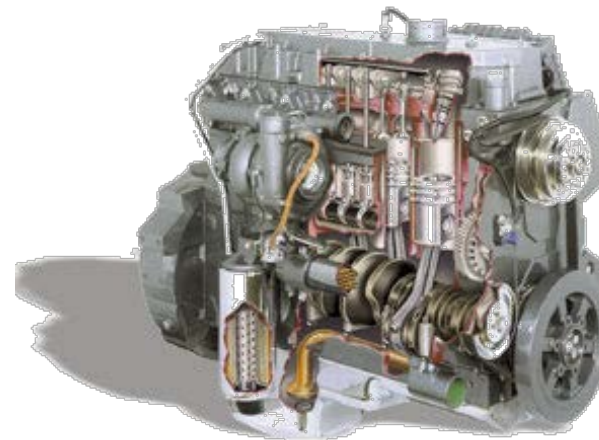


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# High Power Dense Engines



Next Generation Engine



HOTBED Engine



Advanced Fuel Cells



Free-piston Linear Generator



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# Next Generation Combat Engine

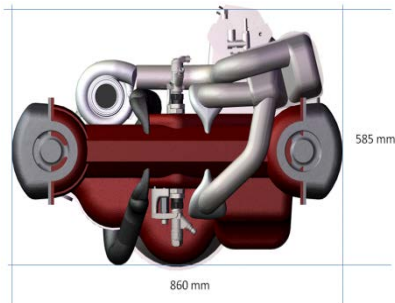
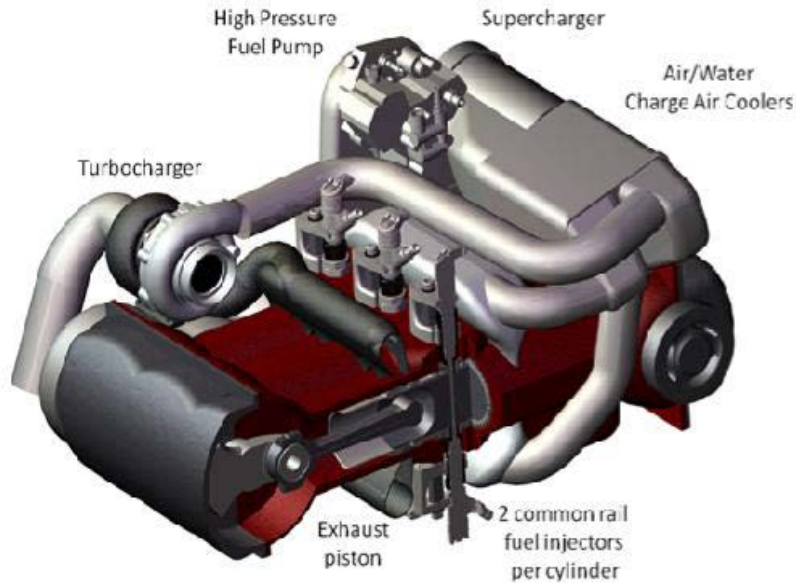


Figure 2a. Front View of 3-Cylinder Engine Concept

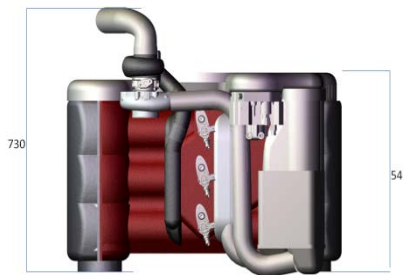


Figure 2b. Plan View of 3-Cylinder Engine Concept

## Opposed piston high output 2-stroke engine

### Payoffs:

- Higher installed propulsion system power density-twice the power in same volume.
- Less volume under armor (weight save)
- Lower cooling system thermal burden with less cooling fan hp draw.
- Improve fuel economy (15-20% improvement).
- Scalable engine family building blocks with high degree of commonality with reduce logistical burden (parts & maintenance).
- Restore mobility capabilities lost due to vehicle weight gains
- Compact design to improve under hood packaging flexibility
- Scalable Engine Family Specification (competitive).

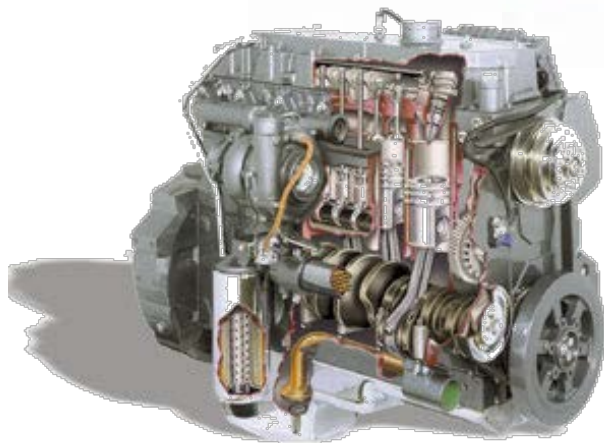


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# High Operating Temperature, High Density Engine (HOTHEd)

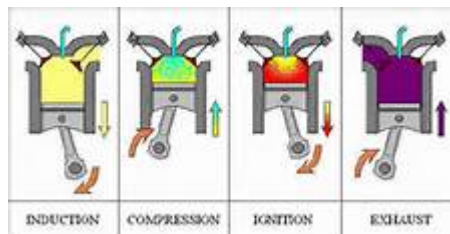


**Higher operating temperature / decreased heat rejection engine.**



## **Payoffs:**

- Engine with increased installed power density for better packaging in future combat vehicles.
- Smaller thermal management system.
- Decreased engine friction for improved fuel efficiency.
- New air charging system for increased power density. Compact two-stage turbocharger systems.



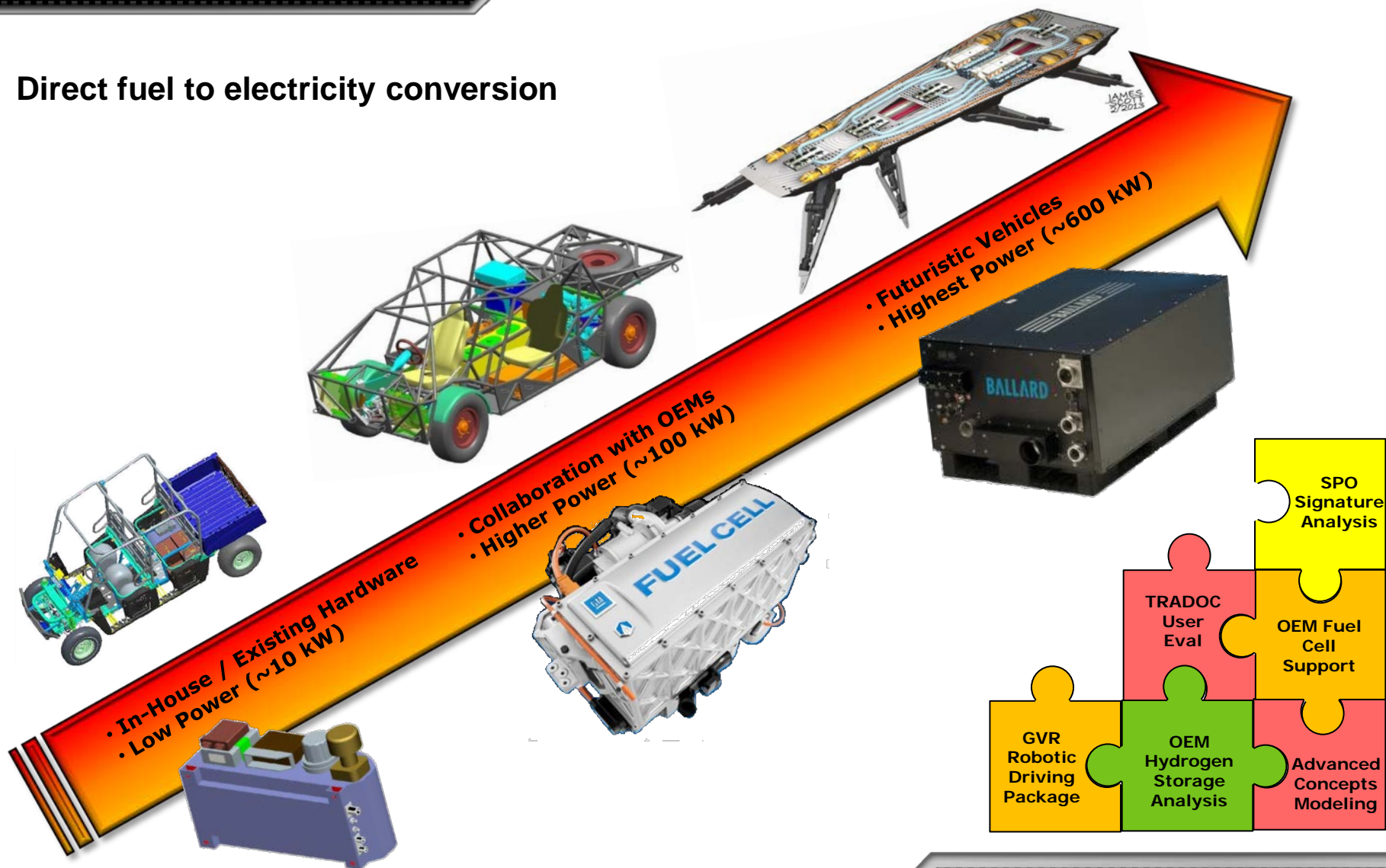


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# Fuel Cells



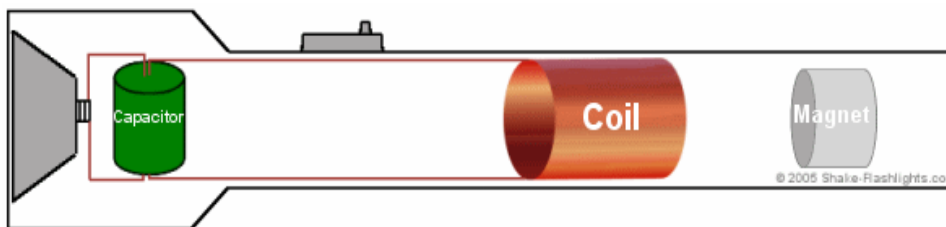
## Direct fuel to electricity conversion





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# Free-Piston Linear Generator Concept



**Faraday** principle of electromagnetic energy to charge





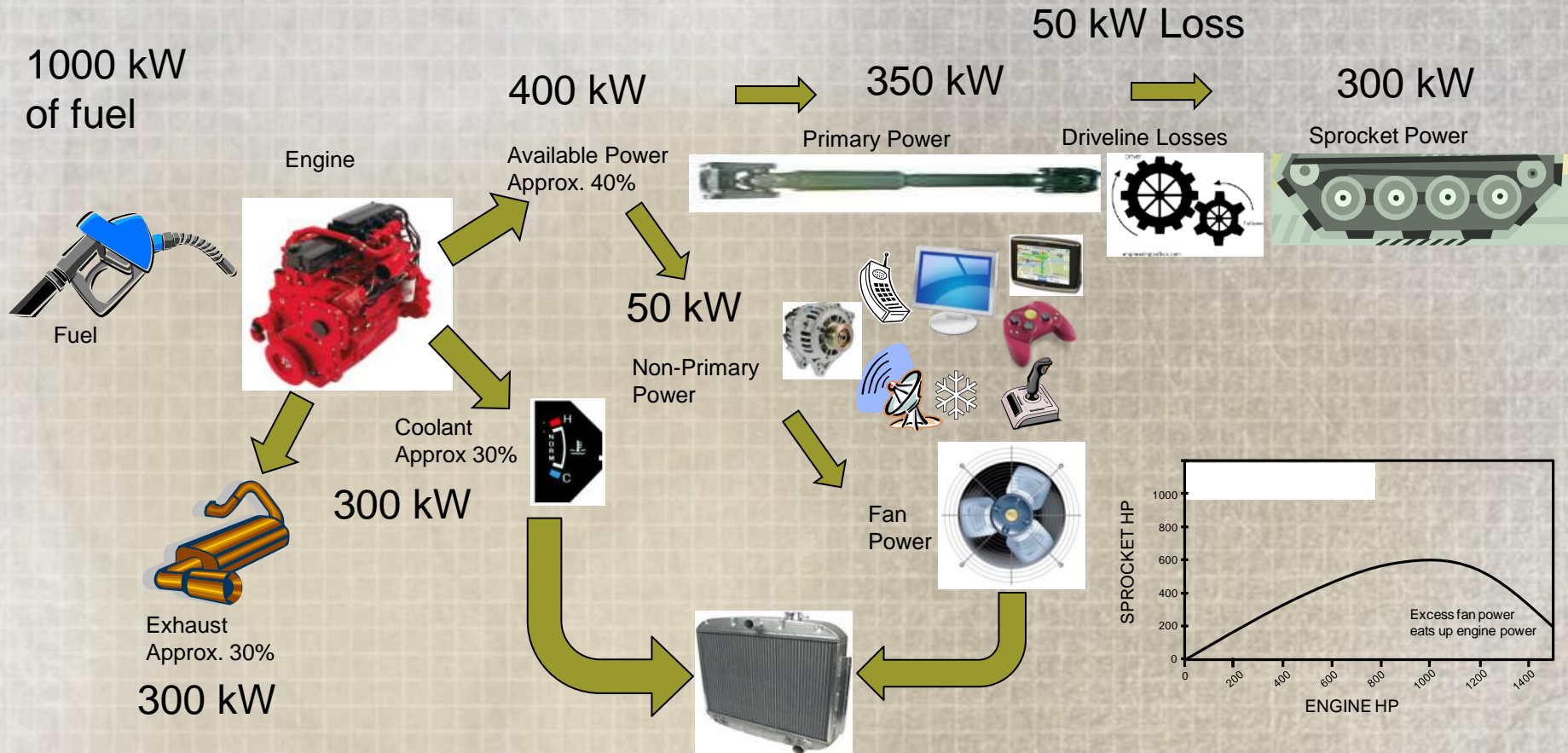
## Advanced Thermal Management Sub Systems





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# Mechanical Drive Propulsion System Losses



Only 30% of fuel energy available at sprocket!!



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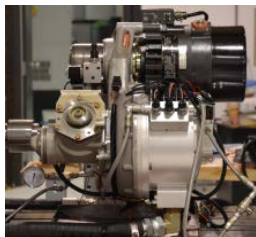
# Near Term Thermal (Improve Components)



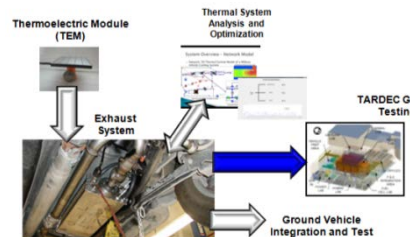
**Improve Existing Component Technologies – efficient power take-off, thermoelectric generator muffler, fan geometry improvement, radiator materials.**



**Efficient  
Fans**



**Geared PTO**



**Thermoelectric  
Generator  
Muffler**



**Electrified Fans  
and Controller  
Hardware**



**Efficient  
Radiators**



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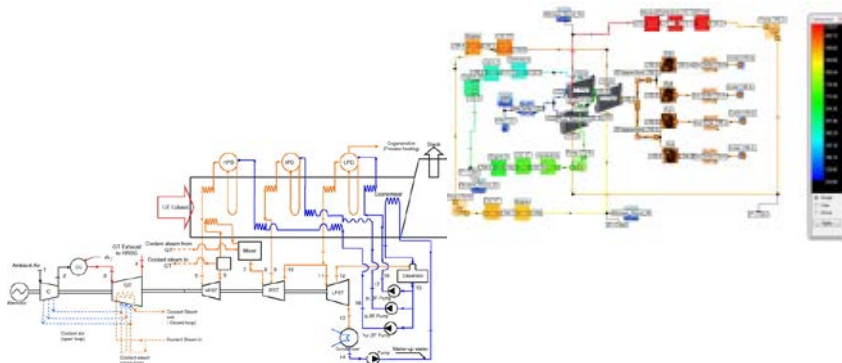
# Mid Term Thermal (Systems Approach)



- **System** – begin integration of thermal loops and architecture optimization, common controller implementation, heat to electrical conversion with engine off
- **Technologies** – adaptable grills, advanced waste heat recovery, solid state cooling, turbocharging /turbocompounding



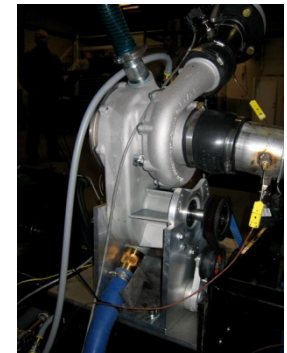
*Advanced Waste Heat Recovery*



*Optimized Cooling Loops*



*Grills*



*Turbocharging*



*Control Module*



*Thermoelectric Power Generation*

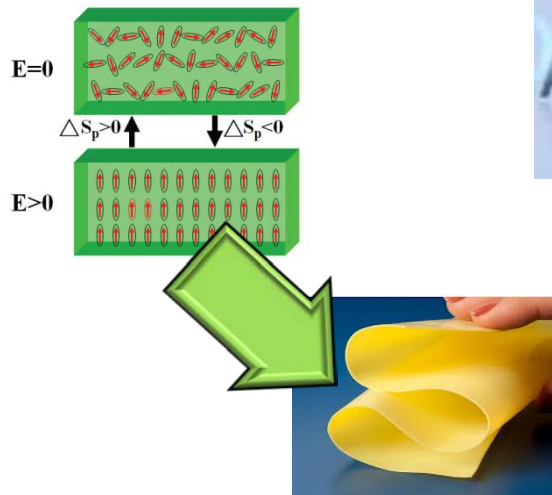


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# Long Term Thermal (System-of-Systems Approach)



- **System** – develop components capable of handling multiple roles within thermal system
- **Technologies** – adaptive insulation, chemical to thermal conversion, thermal to electrical converting hoses, engine component thermal wraps, self-pumping hoses



*Adaptive Insulation*



*Chemical to Thermal Conversion*



*Thermal Wrap*

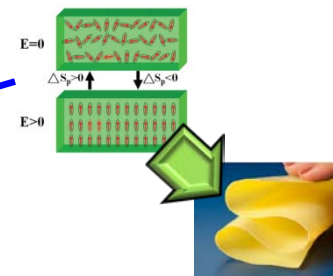


*Advanced Hoses*

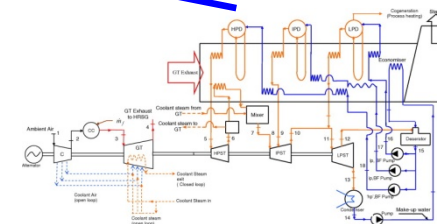


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# Future Thermal Management



**Adaptive Insulation**



**Optimized Cooling Loops**



**Advanced Hoses**



**Intelligent Fans/Radiators**



**Thermoelectric Power Generation**



## *Advanced Electrified Propulsion Sub Systems*



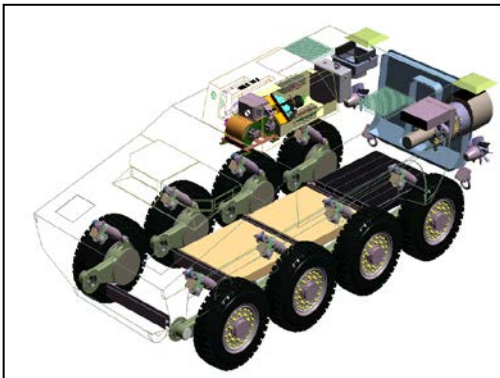


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# Electrified Propulsion – Why?



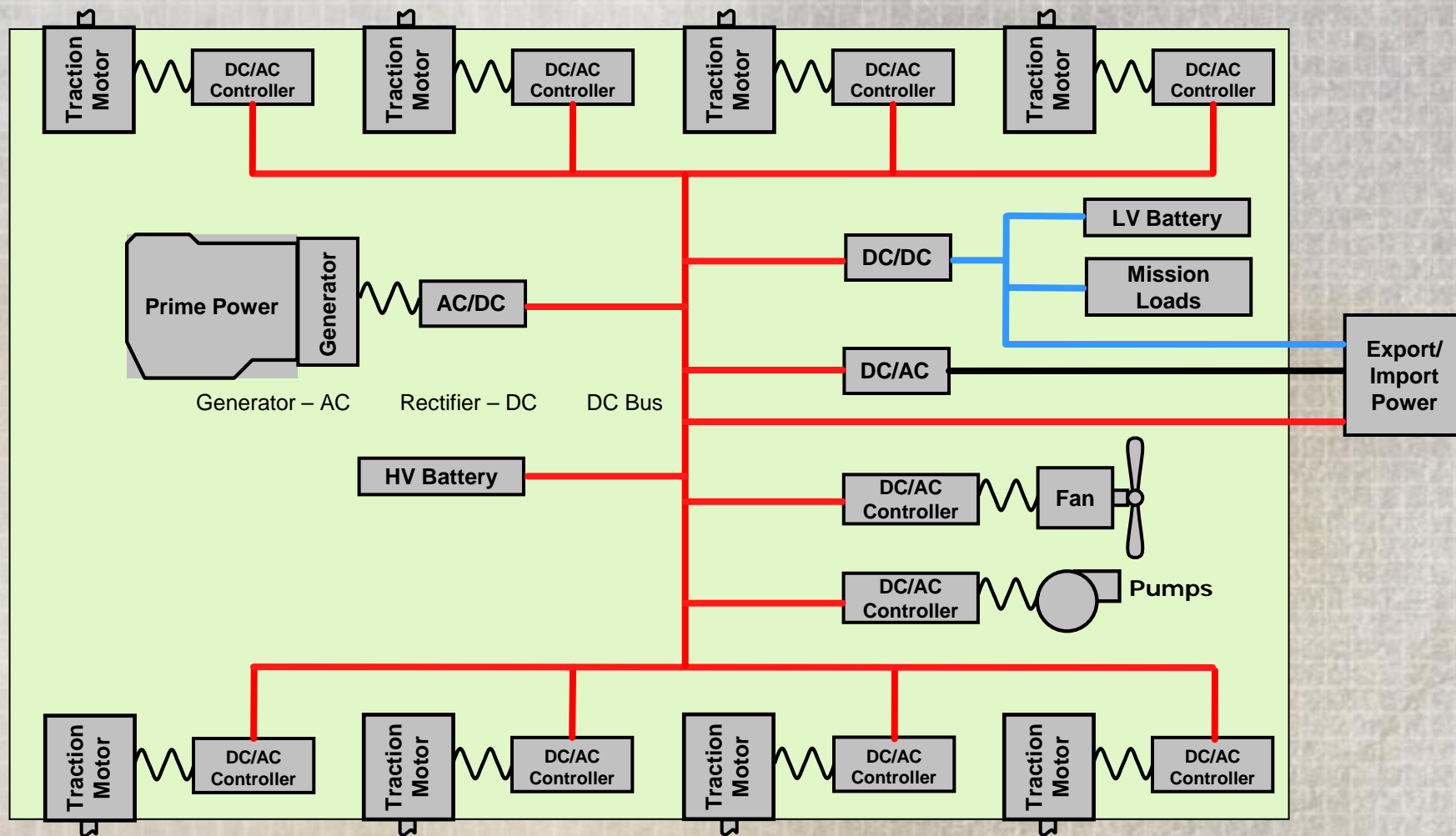
- Enables power for Future Weapons, Defense, and Communications
- Exportable Power Sharing
- Packaging Flexibility
- Enables unique powertrain architectures
- Burst Power for Mobility
- Silent Mobility (reduced thermal and audible signature)
- Silent Watch
- Potential Improvement in Fuel Economy.





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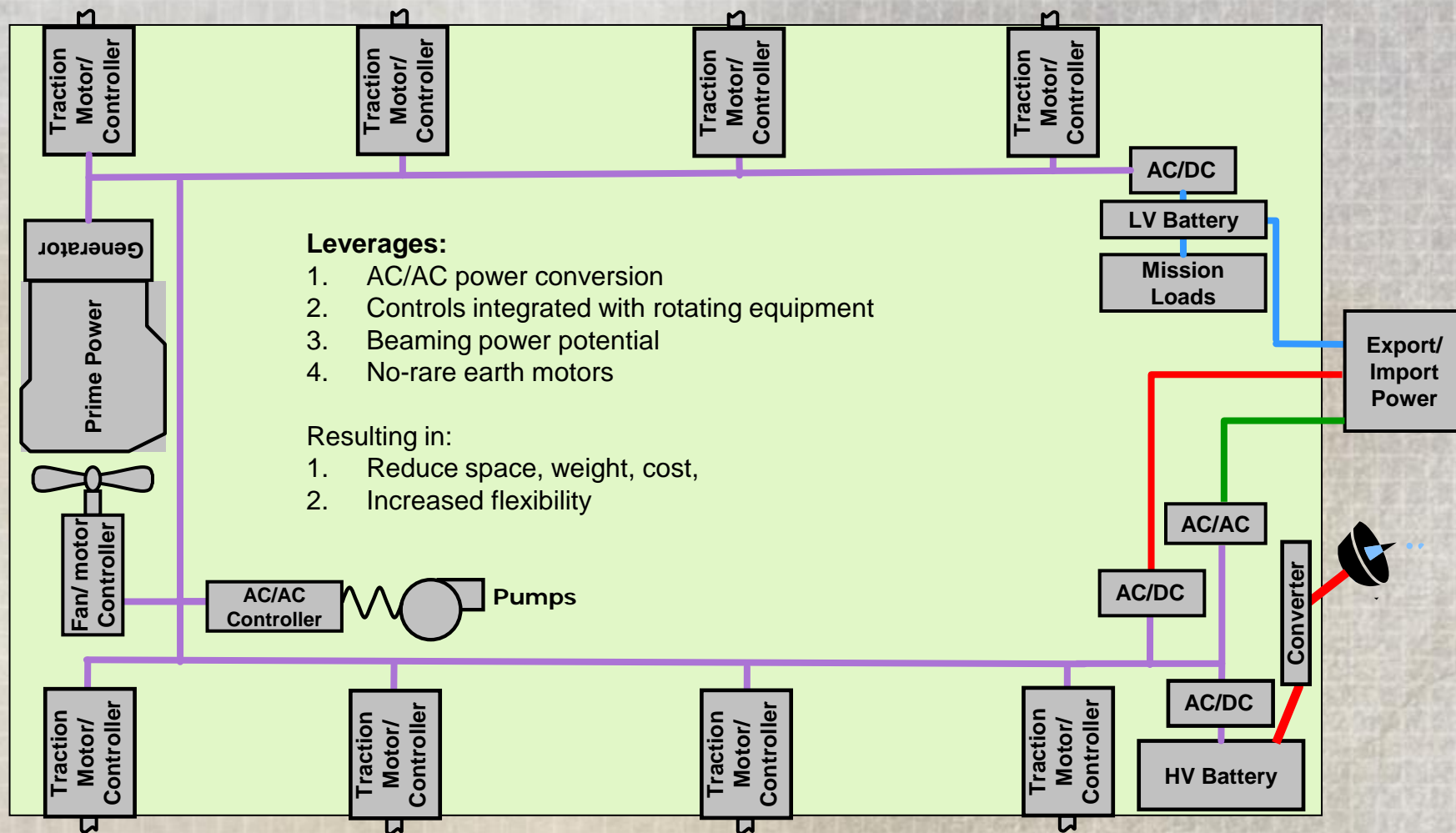
# Electric Drive Architecture Today's approach





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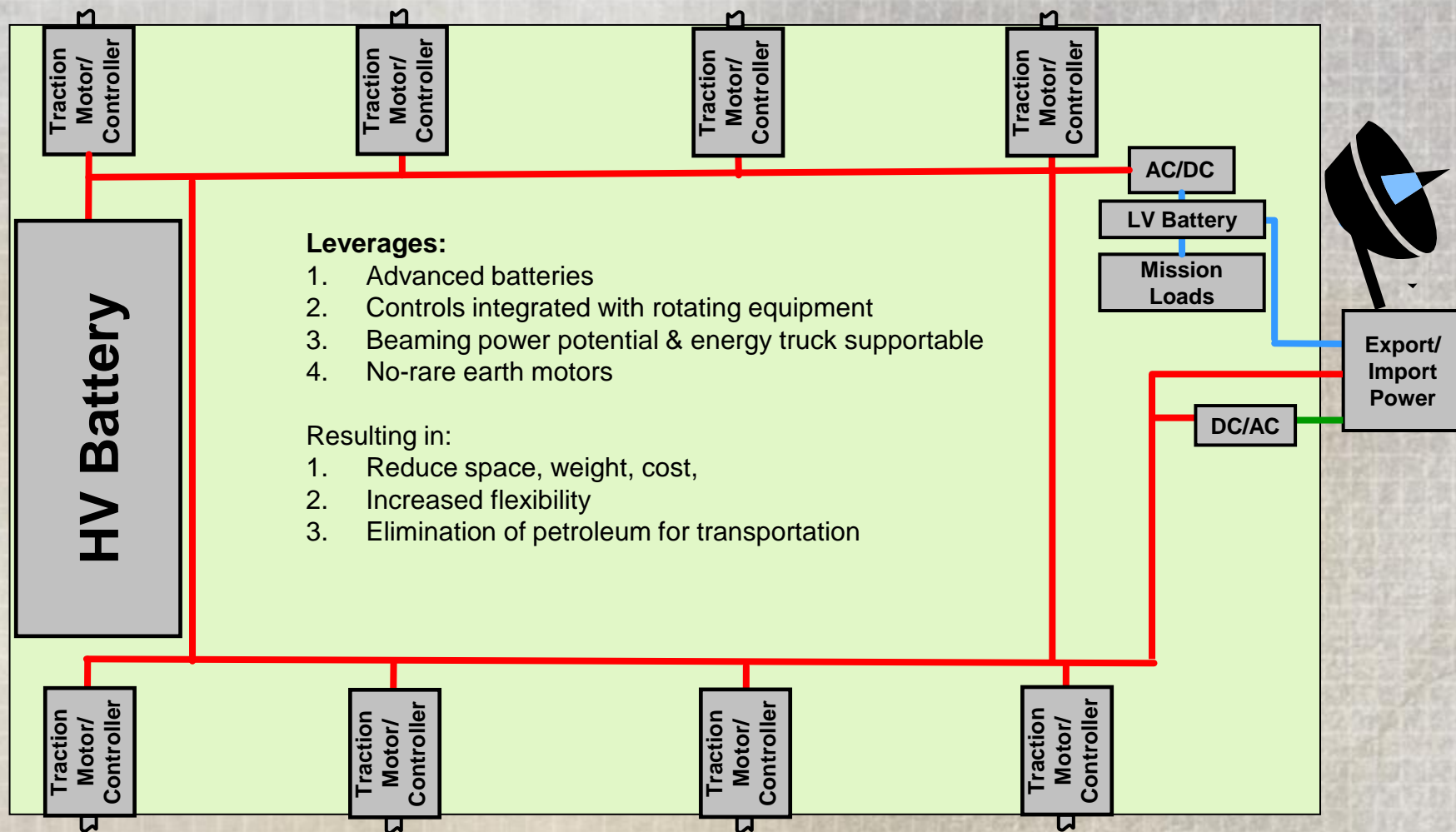
# Electric Drive Architecture Tomorrows approach





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# Electric Drive Architecture Way, way out there approach



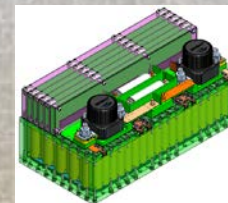
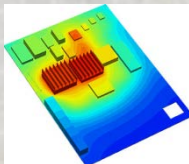


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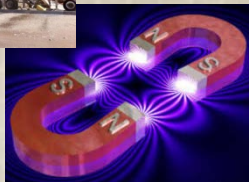
# Art of the Possible – Enabling the Future



*High Temperature electronics*



*Advanced energy storage*



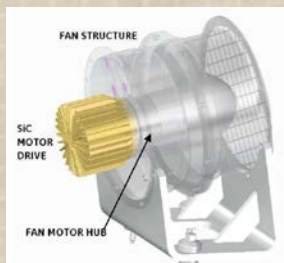
*Non-Rare Earth Magnets*



*High Density electronics*



*Beam Power to vehicles to reduce logistic trail*



*Integrated motor controllers*



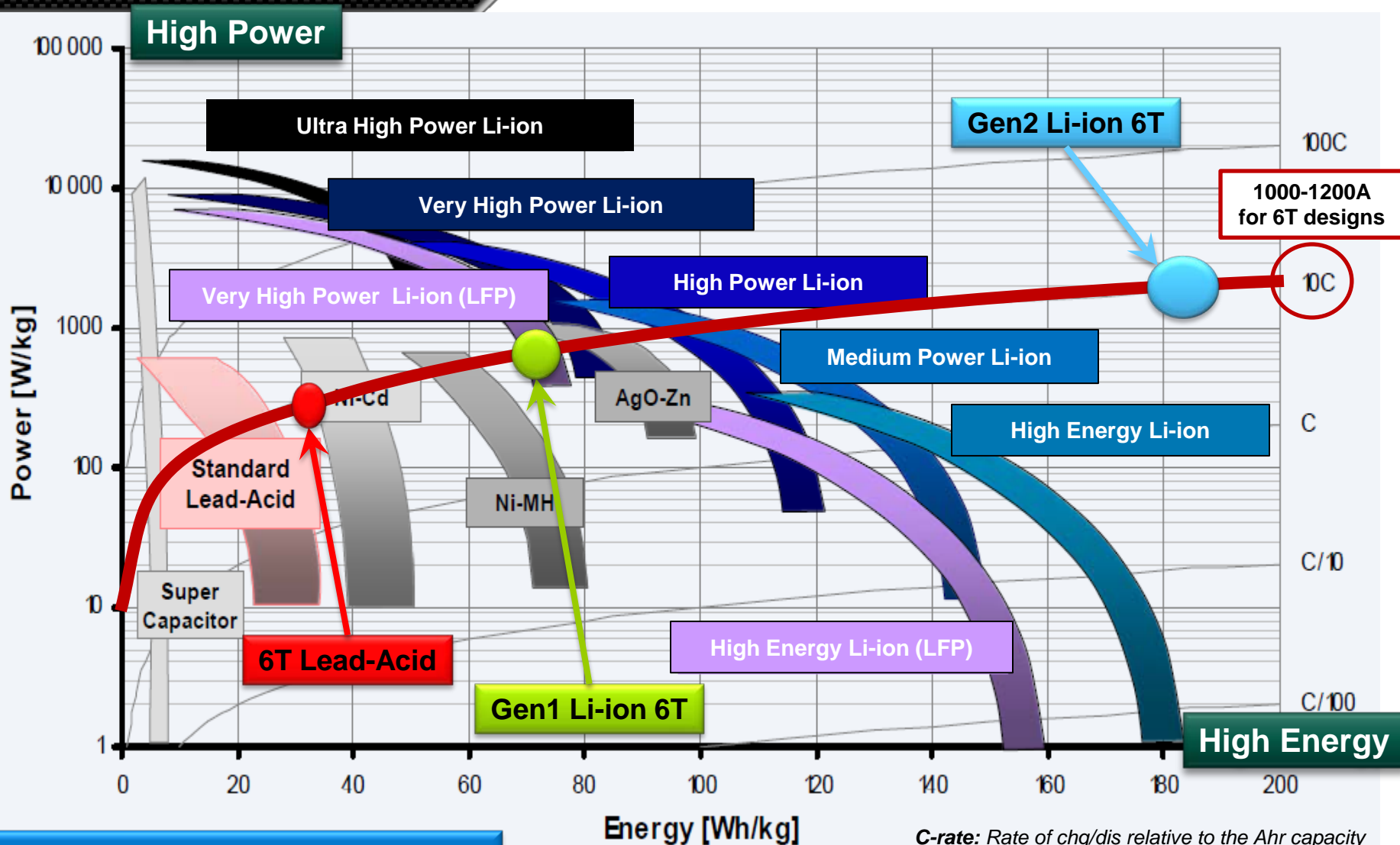
## *Advanced Energy Storage Sub Systems*





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# Power versus Energy

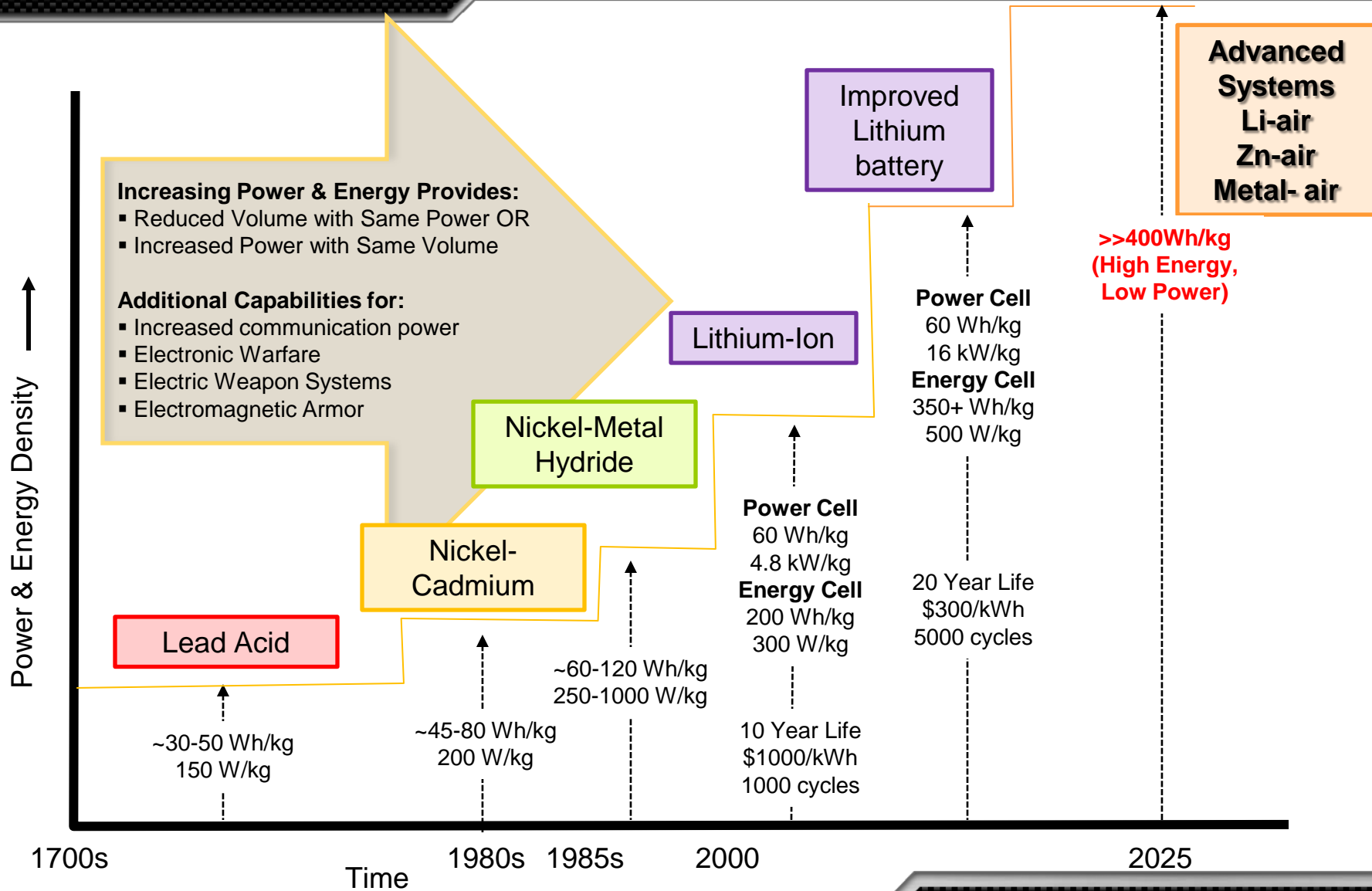


*C-rate: Rate of chg/dis relative to the Ahr capacity  
(1C indicates battery discharged in 1 hour)*



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# Battery Roadmap



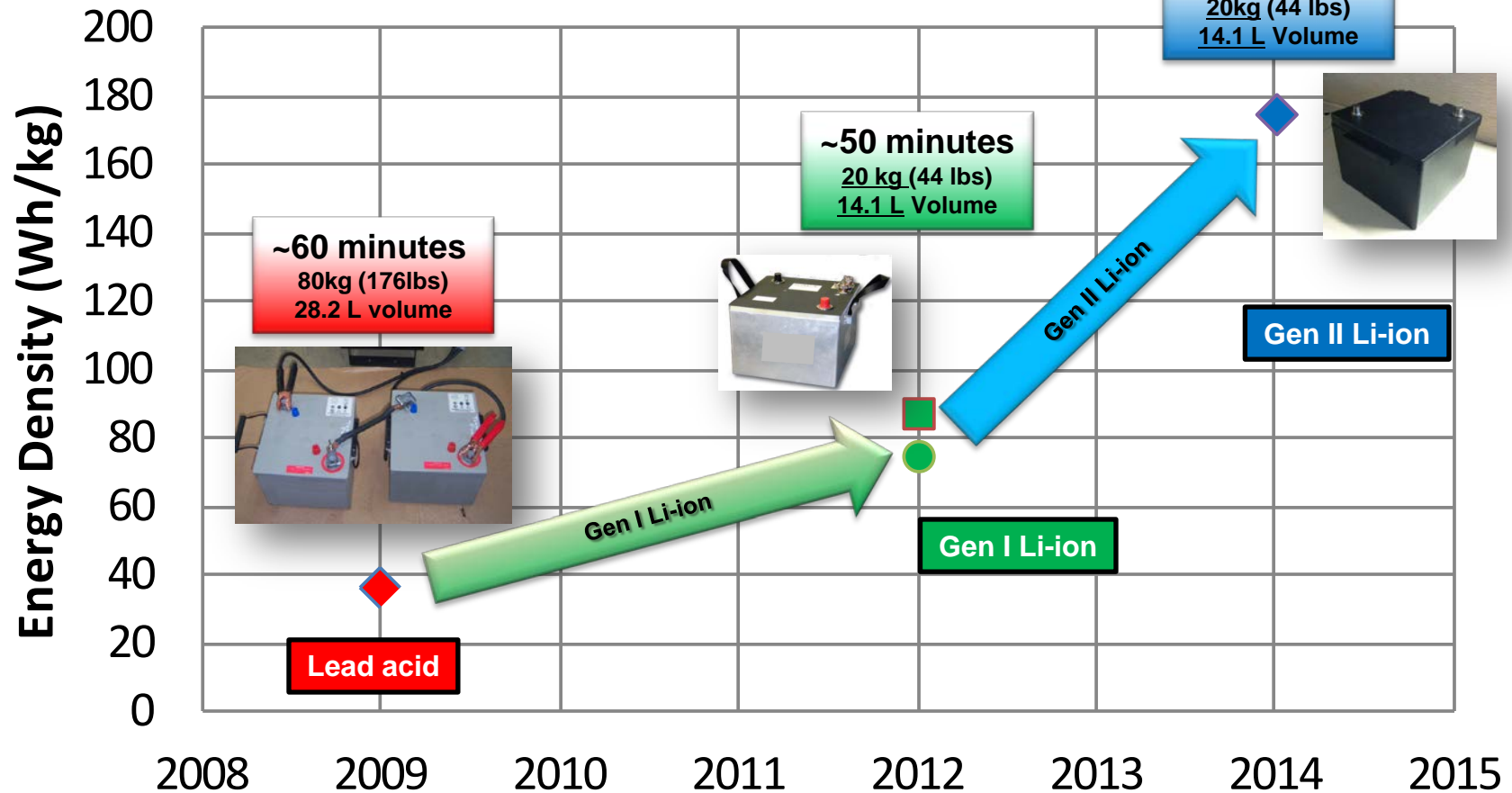


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# 6T Li-ion Battery Development



- Gen1 Li-ion 6T batteries developed and under test
- Gen 1 Li-Ion 6T batteries 2x increase in energy density
- Gen 1 Li-Ion 6t batteries cut weight in half (20kg vs. 40kg)



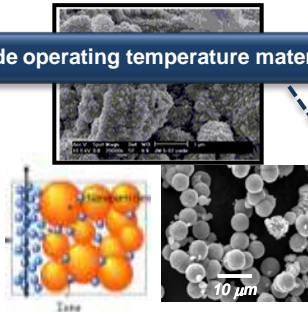


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# High Voltage (600V) High Power Batteries



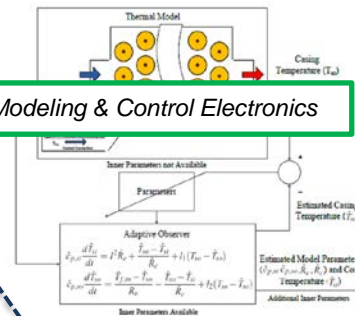
Wide operating temperature materials



High Power materials, cells and packs



Modeling & Control Electronics



Modularized Power Brick



## Power Brick Battery Technology

### Purpose:

- To develop HV battery systems and designs that can meet military shock/vib/environmental requirements.
- To develop compact, modular 600V, high power battery that can be embedded into pulsed power applications to enable multi-use capability.
- To reduce power draw on vehicles for pulse power applications.
- To develop advanced charge control technologies to improve reliability and modularity.

### Product:

- Design concepts, standards and specifications for modularized HV batteries for vehicle applications.
- Modularized high power battery systems that can be reconfigured to support multiple high power applications, including advanced survivability, directed energy and non-lethal weapon systems.

### Payoff:

- Requirements and as the basis for a standardized high voltage battery systems.
- Key enabler for pulse power applications on military vehicle platforms.
- Significant cost reduction.



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# High Voltage (600V) High Energy Batteries



COTS Li-Ion Cells

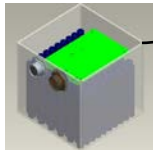


Adapted COTS Li-Ion HV Modules

HE-HMMWV & COTS Li-Ion HV Packs

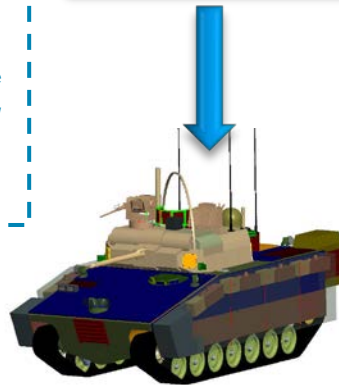


Power Brick Battery Technology & Products



Leverage Products, Specs, & Lessons Learned

Standardized Military HV Battery Module & Pack Specifications



## Purpose:

To develop standardized ground-vehicle high-voltage (HV) battery system & architecture to enable increased commonality as well as reduce overall cost and associated logistics and sustainment burden in support of the Ground Combat Vehicle (GCV) and all other ground-vehicle platforms using high-voltage batteries.

- Develop standardized scalable HV battery modules capable of working in military vehicle environments
- Develop specifications and safety requirements for the HV module and HV battery systems
- Develop and demonstrate prototype HV modules in a HV pack configuration

## Product(s):

- High-Voltage battery module and pack system performance specifications
- Interface control documents
- Testing and demonstration of prototype high-voltage standardized, modular battery system
- In-house HV battery testing & qualification capability

## Payoff:

- Enabler for silent mobility, hybridization, and export power capabilities
- Reduced logistics and sustainment burden through increased commonality and standardization at the module & pack levels
- Increased cycle life
- Advanced electrical & communication architecture to support connection of vehicle-based high-voltage battery system to external microgrids



## Final Mobility Demonstrator Concept Exercise VI



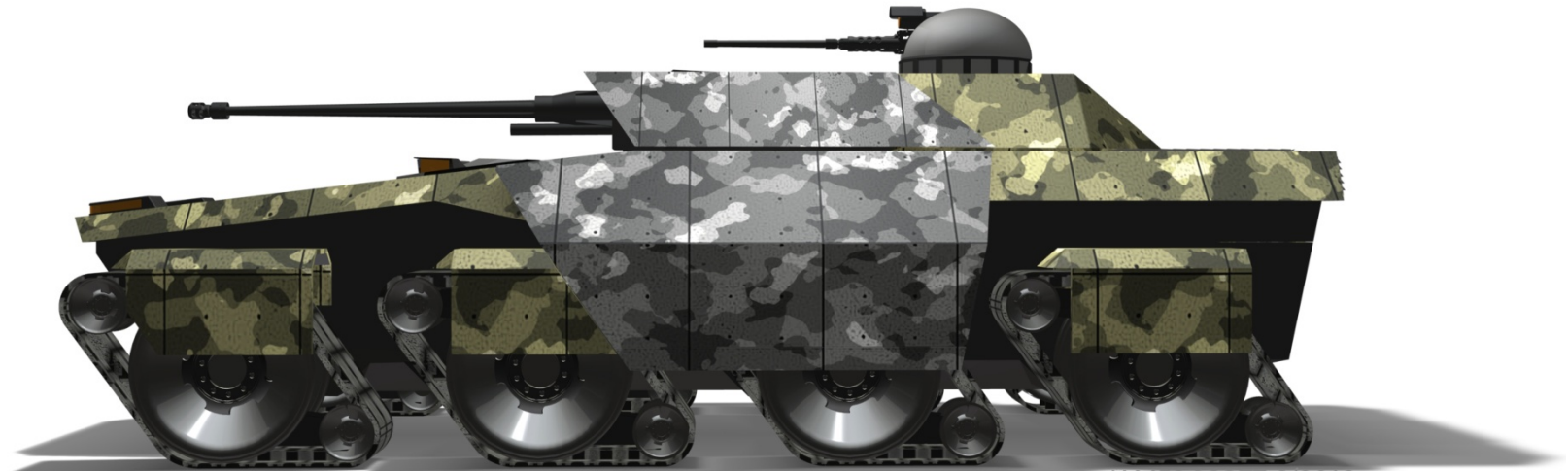


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# Mobility Demonstrator Concept

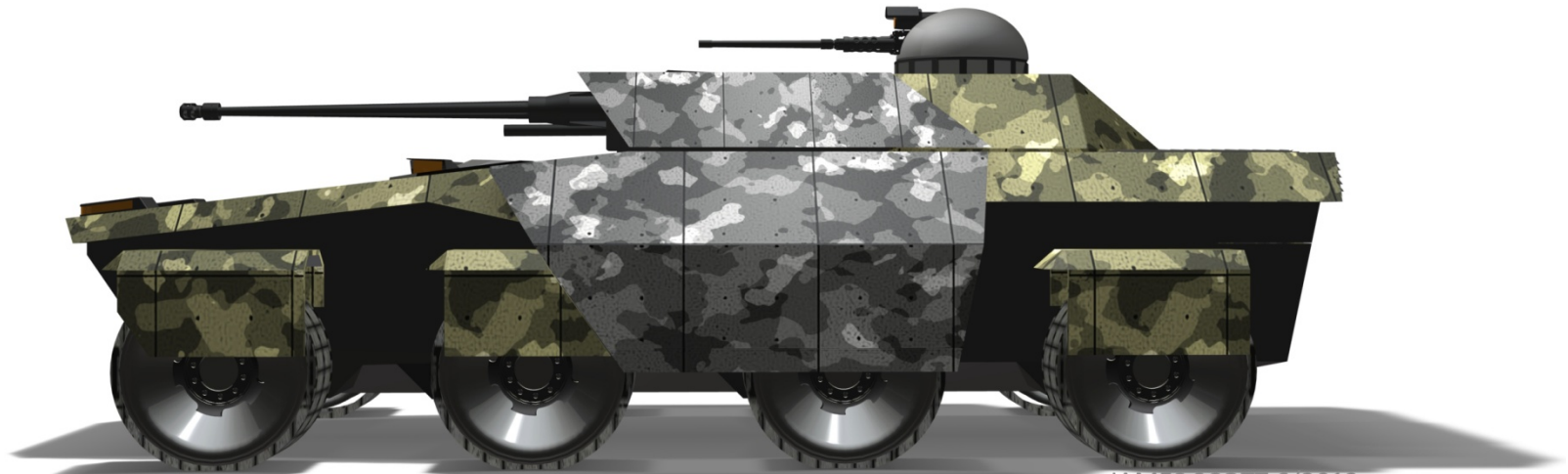


Tracked



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Wheeled



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# Mobility Demonstrator Concept



Tracked



Wheeled



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# Mobility Demonstrator Concept



Tracked



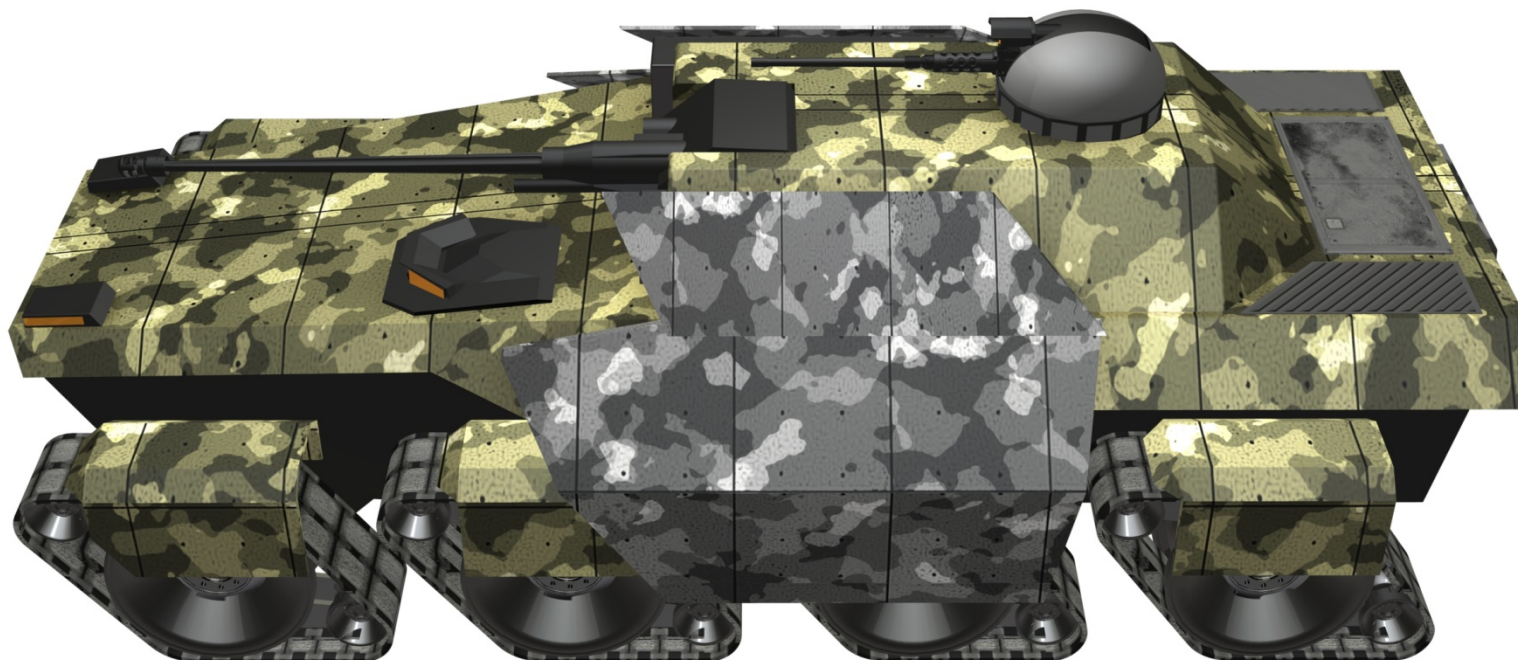
Wheeled





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# Conclusion

